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SIMULTANEOUS AND RUNNING IMPULSIVE LOADING OF CYLINDRICAL SHELLS

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Southwest Research Institute

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LONGITUDINAL OR CIRCUMFERENTIAL) was ascertained for the structures where the overlap in the loading value between the sheet and sprayed explosive load required to produce lethality damage made it possible.

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LIST OF SYMBOLS

Symbol	Definition
D	Cylindrical Shell Diameter (Outside Diameter)
I	Specific Impulse
I_o	Peak Specific Impulse
I_x	Total Impulse
L	Cylindrical Shell Span Length
M	Ballistic Pendulum Mass
R	Cylindrical Shell Radius (Outside Radius)
h	Height Above Shell Base
ℓ	Center of Percussion of the Ballistic Pendulum
δ	Pendulum Displacement
θ	Rotational Coordinate about the Axis of Cylindrical Symmetry
τ	Period of the Ballistic Pendulum

I. INTRODUCTION

This report contains the results of an experimental program undertaken to investigate various aspects of the impulsive loading of certain cylinderical shell test specimens simulating X-ray blow-off loading. There were twenty-seven tests conducted on 6-inch diameter (O. D.) aluminum and lead cylinders, some of which were wrapped with silica phenolic heat shield material, and all of which had an L/D for the loaded region of 0.9. Loading was accomplished using sheet explosive (PETN in a latex binder), silver acetylide-silver nitrate spray deposited on the structure, or some combination of these explosives with or without tamping. Various methods of explosive initiation were tried, and simultaneous or running loads were obtained. All loading was performed to simulate a cosine load distribution circumferentially over 180° of the cylinder with the maximum specific impulse along a crown line over the span length of the specimen. For many of the tests, strain gage data were obtained at several locations along the crown line measuring circumferential (hoop) or axial strains. Wall displacement measurements were made along the crown line under the dynamic conditions for some tests.

The object of this testing was to determine what loads were necessary to produce minimum lethality damage to the structures tested and to provide data to verify existing computer codes which predict damage on the basis of a known loading and the structural characteristics. It was also determined through this testing that there were significant differences in structural damage levels obtained for the same loading levels on a given structure depending on the method of initiation used. Specifically, it was determined that sheet explosive (SE) with initiation techniques which produce running loads would cause greater damage levels to some of the structures than an equivalent, simultaneously initiated silver acetylide-silver nitrate load (SASN). It was also determined that there was little difference between damage levels produced by circumferential and longitudinal running loads for the same load level on phenolic bonded aluminum cylindrical shells. Simultaneous loading of the phenolic bonded structures could not be accomplished at sufficiently high impulse levels to cause minimum lethality damage.

II. EXPERIMENTAL PROCEDURE

A. General

In a typical test, one of the cylindrical test specimens, whose characteristics are described in Section II-B, was mounted in a holder (described in the same section). The specimen was instrumented with strain gages and displacement probes (with the exception of "non-instrumented" tests) as described in Section II-D. One of the loading techniques described in Section II-C was applied to the cylinder, and output data consisting of the ballistic pendulum displacement, strain gage and displacement probe outputs, etc., were recorded as described in Section II-D.

Figure 1 shows a "before and after" view of a typical test. The results relating characteristics of the test specimen with the loading, instrumentation, and damage level for each of the tests performed are described in Section III.

Because of its hazardous nature, testing was performed both at our indoor explosive testing facility and at our outdoor range designed for explosives work. These areas contain standard safety equipment, including conducting floors, ventilation, limited access, etc.

B. Test Structure Characteristics

1. Types of Structures Loaded

There were four types of test structures blast-loaded during the course of these tests. Tests on shells 1 through 13 were performed on cylindrical test specimens consisting of 6-inch diameter (O. D.) metal shell substrates upon which was bonded a 0.25-inch thick layer of silica/phenolic. (Reliabond 398 adhesive film was the bonding agent.) The silica/phenolic was MX-2600 straight tape, manufactured by Fiberite Corporation, impregnated with phenolic, wound onto the substrates, and heat cured. The aluminum substrates were Al-6061-T6. The lead substrates were an alloy supplied by BRL. Tests 14 and 15 were SASN tests on phenolic bonded substrates which yielded no deformation to the structures. Tests 16 through 29 were run on bare metal substrates, 6-inch diameter (O. D.). Table I gives the detailed dimensions of the test cylinders, and Figure 2 shows typical phenolic bonded and bare substrate structures.

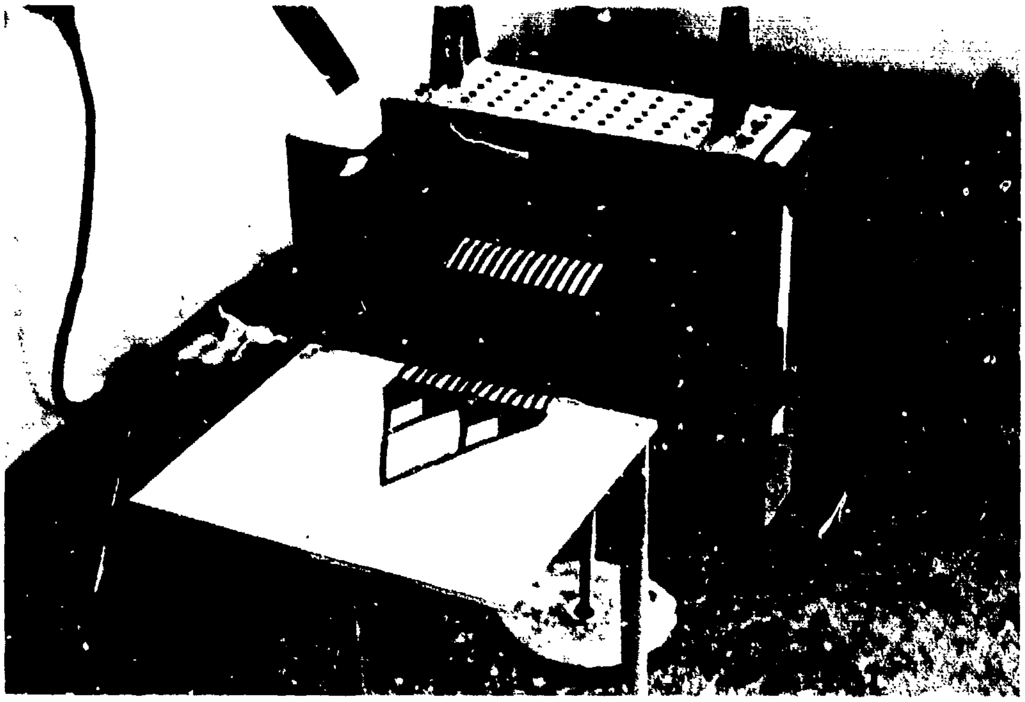

Figure 1a. Structure Mounted on Pendulum Prior to Test Showing Layered Stripped SE Load

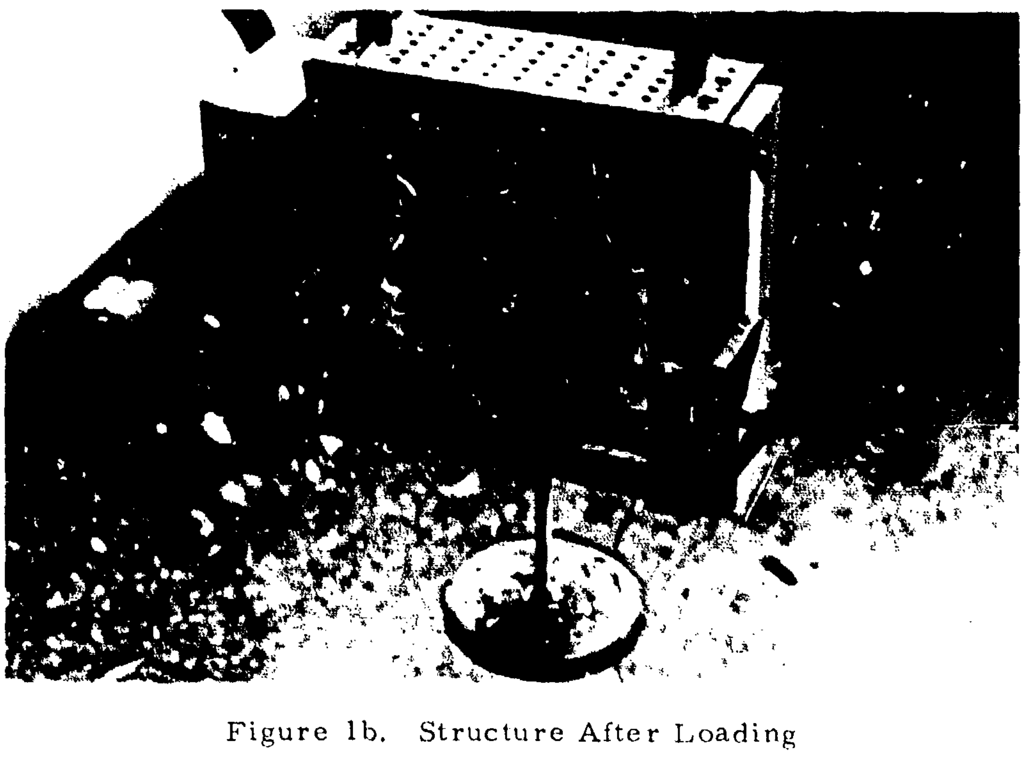

Figure 1b. Structure After Loading

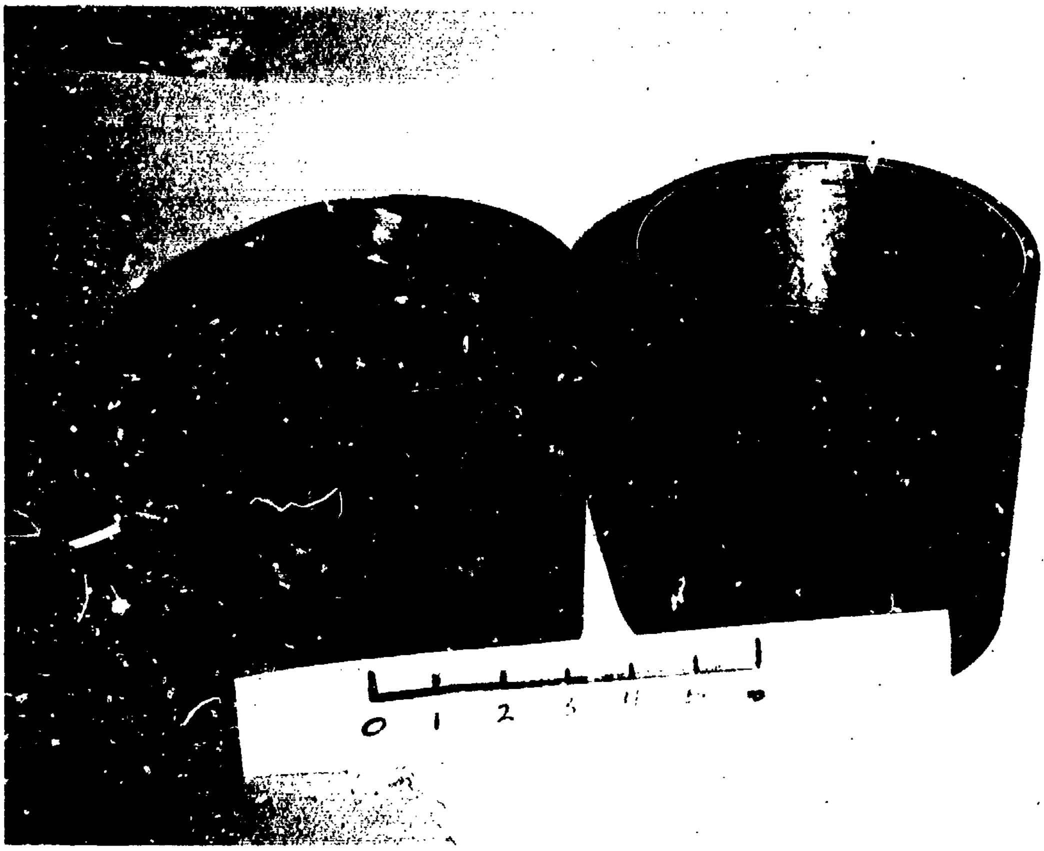

Figure 2. Bare and Silica/Phenolic Bonded Aluminum Cylindrical Test Structures

TABLE I

DIMENSIONS OF TEST CYLINDERS

Type	O. D. (in.)	Substrate Wall (mils)	Phenolic Wall (mils)	Length (in.)	Span Length (in.)
Phenolic Bonded Al	6.50	42	250	6.50	5.25
Phenolic Bonded Pb	6.50	64	250	7.00	5.25
Bare Al	6.00	42	---	6.50	5.25
Bare Pb	6.00	64	---	6.50	5.25

2. Mounting of Structures

Figure 3 shows the disassembled test cylinder holder and the holder with a test fixture in place. All test fixtures were rigidly clamped at their ends such that a 5.25-inch length of the specimen between the end clamps was free to deform when loaded (i.e., 5.25-inch span length). The clamping at the cylinder ends held the planes of the cylinder ends parallel to each other before a test, which meant the cylinder walls should have to tear during loading before the cylinder ends would be pulled free of the holder. Instances where the cylinder ends pulled free of the holder during the course of a test are mentioned in the Results section. The end plates of the test cylinder holder were held 5.25 inches apart by a 1.5-inch diameter steel rod which was fitted into a pilot hole in the end plates to hold them rigidly parallel to one another. The end plates were fitted into the ends of the test cylinders, and the ring clamps held the ends in place.

C. Types of Loading

All of the cylindrical test specimens blast-loaded in these tests were loaded over 180° of their surface in the so-called "frontal cosine" loading configuration, i.e., a load in which the specific impulse, I, varies circumferentially about the cylinder such that

$$
\begin{aligned}
I(\theta) &= I_o \cos\theta \qquad -90^\circ \le \theta \le 90^\circ \\
I(\theta) &= 0 \qquad\qquad 90^\circ \le \theta \le -90^\circ
\end{aligned}
\tag{1}
$$

where I_o is the peak tap* level along a crown line at $\theta = 0^\circ$ (I is

*1 tap = 1 dyne-sec/cm^2.

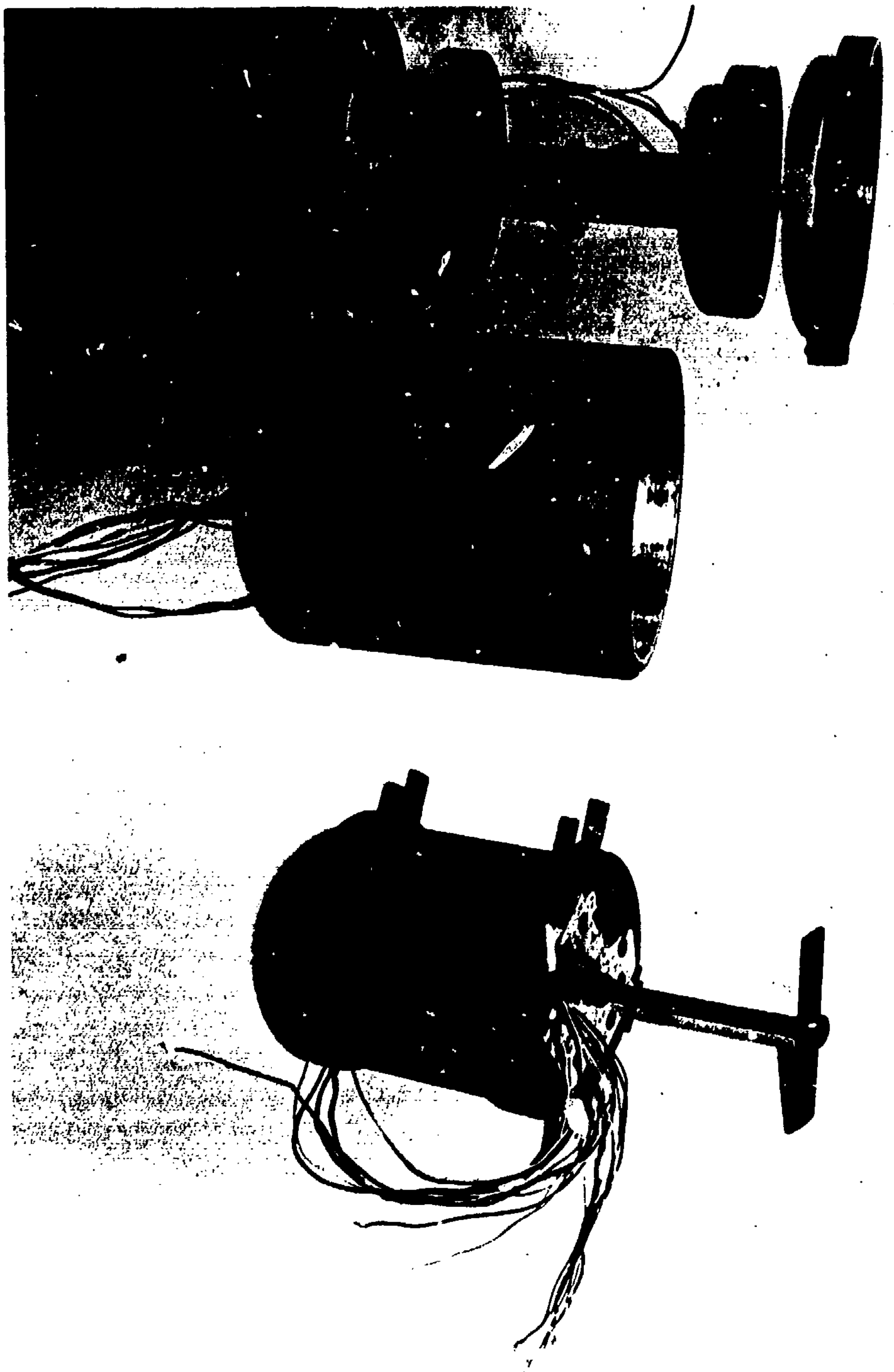

Figure 3. Test Cylinder Holder and Holder with Test Structure in Place

constant for a given θ in the cylinder axial direction). Methods for obtaining a cosine load varied with the loading technique to be described. The types of loading fell into one of two categories: "simultaneous" loads and "running" loads. Simultaneous loads are those in which the peak overpressures attained at any two points on the surface area loaded fall within a time window of 2 μsec or less of one another. These loads were obtained by the use of the light-initiated silver acetylide-silver nitrate (SASN) technique. Running loads are those in which the blast loading is initiated at one point, or along a line, and the time at which peak overpressures are attained at any point on the loaded area is a function of the propagation velocity of the reaction in the explosive and the distance of that point from the nearest point of initiation.

1. Simultaneous Loads

a. Light-Initiated SASN

The technique of blast loading structures with light initiable SASN has been described in numerous papers and reports.(1-4)* Briefly, the technique used in this work was as follows. The cylindrical test specimens were mounted in the rigid fixture (as described in Section II-B-2) such that the cylinder ends were held fixed. A sheet of 15-mil aluminized Mylar was glued to the cylinder wall with contact cement. The test specimen was then mounted, clamp and all, on a rotation table, such that the cylinder could be rotated about its axis. Figure 4 shows a test specimen mounted on the rotation table. A circular conducting probe of 0.75-inch diameter, faced with the radius of curvature of the cylinder, was located 0.2 inch from the cylinder wall. This probe acted as one plate of a parallel plate capacitor, the other plate of which was the aluminized Mylar bonded on the cylinder. The probe could be moved vertically parallel to the cylinder axis without changing the probe-to-cylinder spacing. An initial baseline was taken with this apparatus at two axial locations by measuring the inverse of the capacitance of this parallel plate air gap capacitor as the cylinder was rotated through 180°. Silver acetylide-silver nitrate in an acetone slurry was then sprayed onto the fixture such that the residual SASN (after the acetone had evaporated) varied in thickness over a 180° rotation of the cylinder in the desired cosine function. This distribution could be verified by measuring the change in capacitance of the probe-Mylar parallel plate capacitor as the cylinder wall coated with the SASN was rotated past the probe. The SASN acts as a dielectric and has a sufficiently high dielectric constant so that the capacitance measured is inversely proportional to the SASN layer thickness beneath the

*Superscript numbers in parentheses denote references which will be found on page 39 of this report.

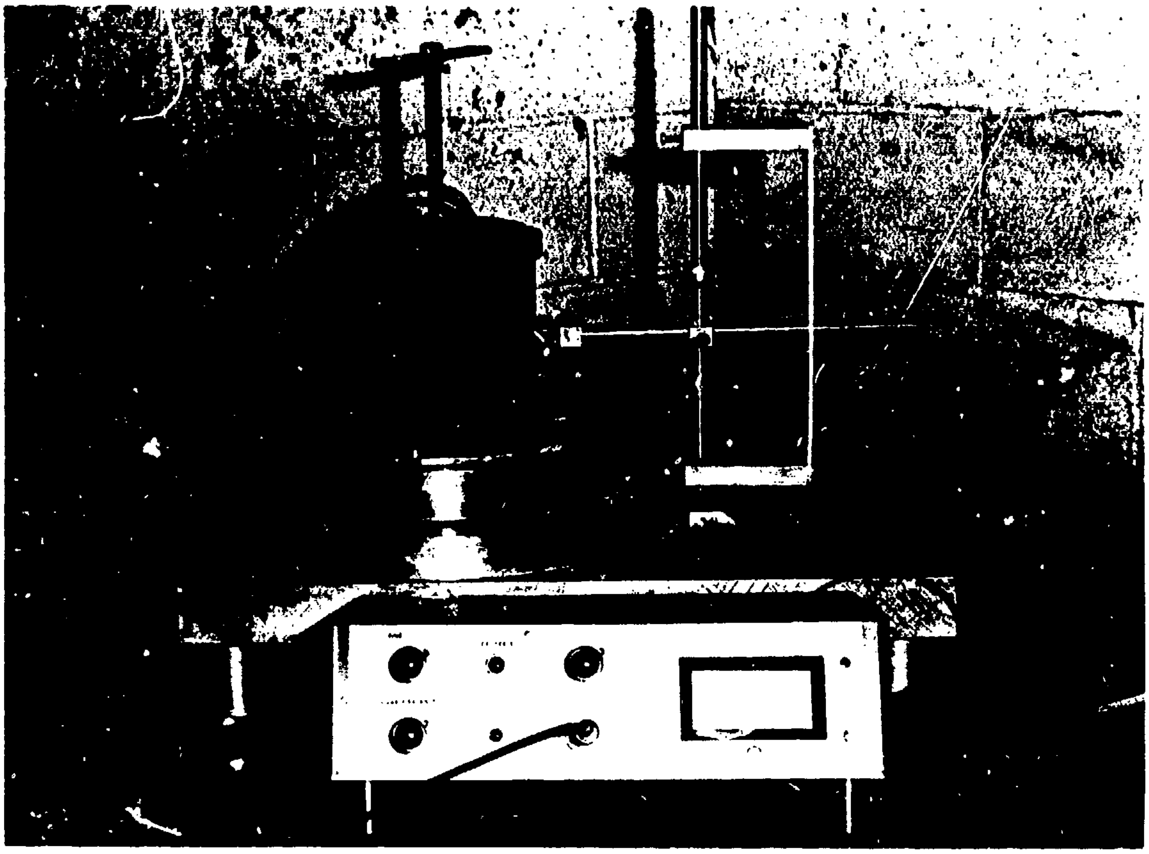

Figure 4. Test Cylinder Mounted on Rotation Table

probe. A trace of a typical SASN thickness distribution may be seen in Figure 5.

After a test fixture had been sprayed with SASN in the manner described, it was removed from the rotation table and mounted on a ballistic pendulum such that the vector direction of the peak impulse on the crown line ($\theta = 0°$) was in the direction of the pendulum swing (see Figure 6). Xenon lamps (approximately 8 inches long) were made by evacuating 18-mm O.D. pyrex glass tubing and backfilling with (1/3) atmosphere xenon. A lamp was mounted in an aluminized Mylar reflector system within inches of the test fixture crown line and parallel to it. Three 8.5-μfd capacitors in series were charged to 20 kv with a high voltage source. This capacitor bank could then be switched across the lamp through a rail-gap switch. The high voltage ionized the xenon in the lamp, and the electrical energy stored in the capacitor bank was dumped through the lamp causing a brilliant flash of light. This flash in turn simultaneously detonated the light-initiable SASN at thousands of points over the surface area on which it was deposited. Simultaneity of detonation could be verified by the density of initiation points appearing on the smoke trace left on the Mylar after each test. The specific impulse delivered to the test specimen varied with the SASN thickness, having a peak along the crown line of I_o. Values for I_o were obtained from the ballistic pendulum measurements or from the measurements of the thickness of the SASN (areal density) on the crown line and an areal density versus impulse curve for SASN.

b. Tamped, Light-Initiated SASN

The maximum specific impulse attainable from spray-deposited SASN alone is approximately 10 kilotaps. For the test cylinders consisting of phenolic bonded on Al substrates (see Section II-B-1 for test fixture description), it was not possible to obtain minimum lethality damage levels with this low peak tap level. Accordingly, for some simultaneous loads, cylinders were sprayed with SASN as in the previous section, but a 0.125-inch thick clear plastic tamper was used to enhance the blast effect of the load without interfering with the simultaneity of the detonation. A clear plastic sheet was slump-molded to the radius of curvature of the cylinder such that it formed a semi-cylinder of a height equal to the test cylinder span length (5.25 inches--see Figure 7). This plastic semi-cylinder was hinged to the holder once the specimen was sprayed with the SASN, and could be moved into place remotely. In place, it covered half the test cylinder, sandwiching the SASN load between the plastic and the test cylinder wall. The SASN could still be light-initiated through the transparent plastic without affecting simultaneity, but the blast effect of the SASN was enhanced by the tamping effect created by the inertia of the plastic and the trapped explosive gases between the plastic and the cylinder wall.

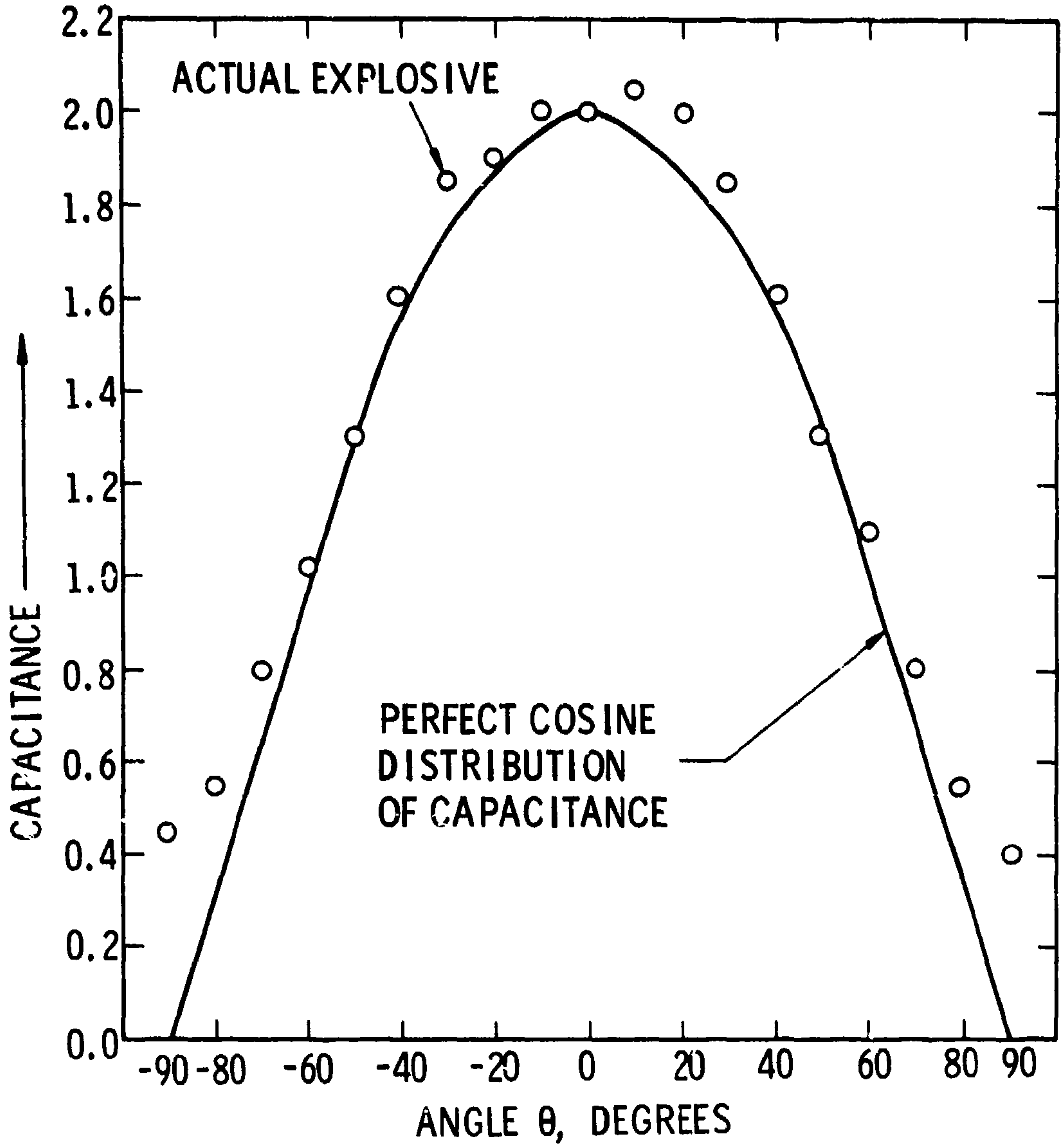

Figure 5. Cosine Distribution of SASN Explosive
Used for Test #25

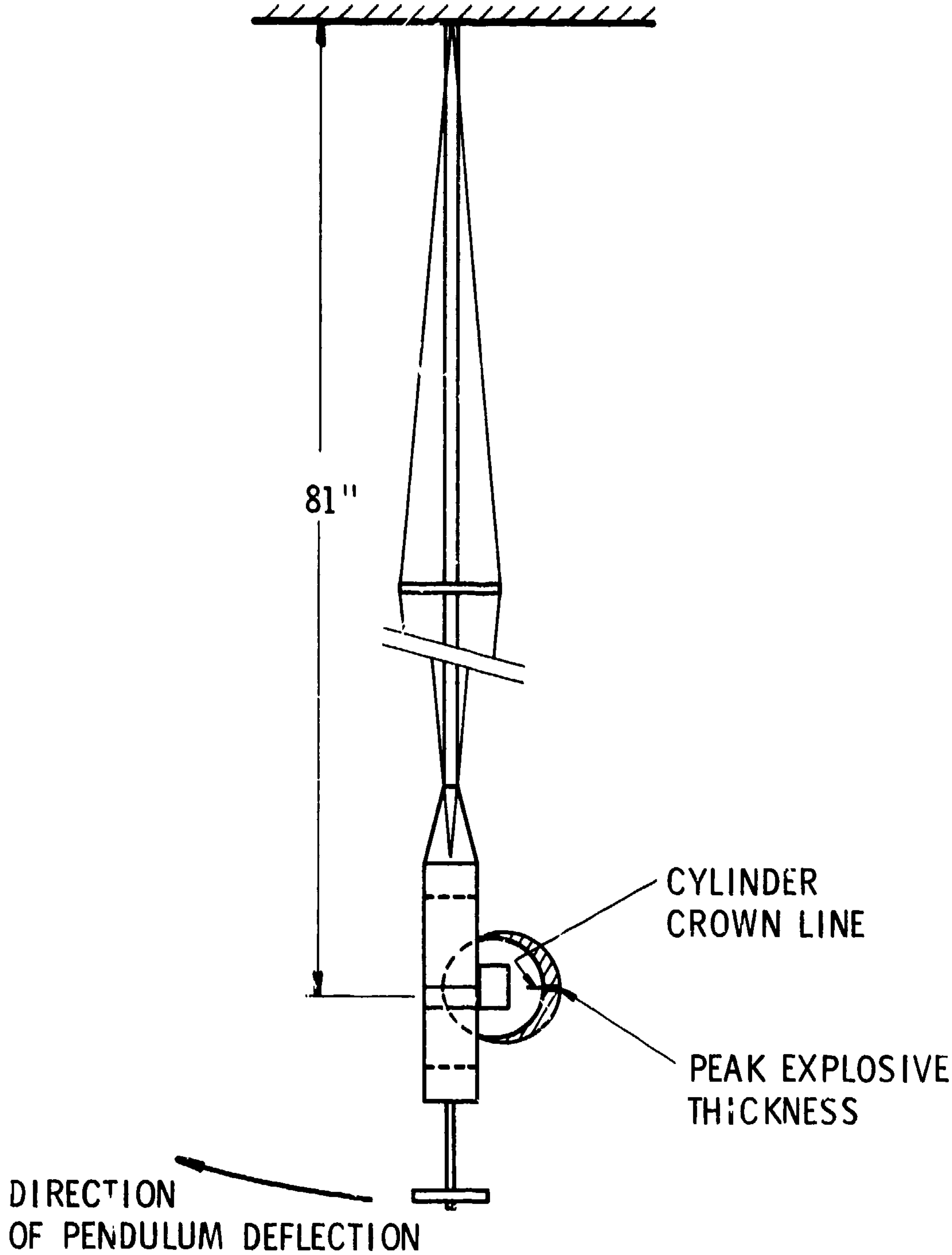

Figure 6. Ballistic Pendulum with Mounted Test Cylinder

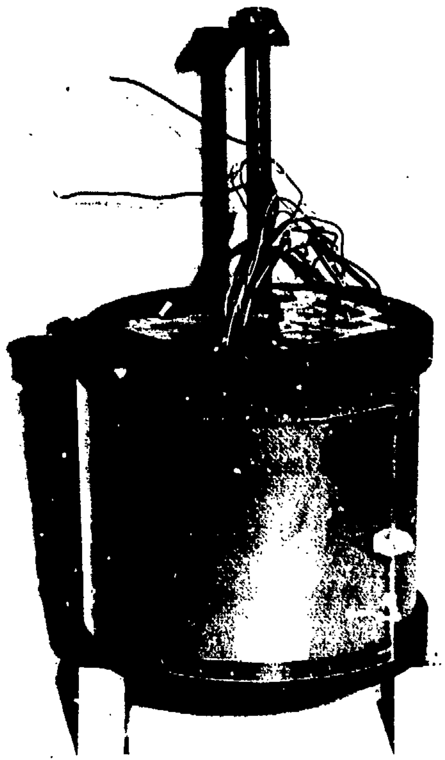

Figure 7. Test Cylinder with Tamper in Place

2. Running Loads

a. Sheet Explosive (SE) Loading

The technique of blast loading structures with sheet explosive (SE) is described in several reports.[5-6] Briefly, the pertinent characteristics of the explosive used in this work are as follows. Dupont Detasheet D in 15-mil thickness was used exclusively. It has a specific impulse of about 9 kilotaps, for a solid sheet. Increasing the sheet explosive thickness increases the specific impulse obtainable on detonation approximately linearly, but sheets of thickness less than 15 mils cannot be made to detonate completely with repeatability. Consequently, to get specific impulse levels less than 9 kilotaps, the SE has to be "stripped". In this process, parallel strips of SE of 0.1-inch width are spaced 0.4 inch apart (i.e., strip center spacing), reducing the average specific impulse over the loaded area to one fourth that for a solid sheet (i.e., 2250 taps).*

A cosine load configuration may be approximated by building up several layers of explosive. The more layers used, the closer the charge may approximate a true cosine load. Discontinuities in loading remain at the edges of the layers with this technique, however, regardless of the number of layers used and the minimum specific impulse obtainable at any point under the loaded area is 2250 taps.

The SE loading technique used in this work was as follows. SE loads were "built up" of layered pieces of stripped and solid 15-mil SE which were glued on a paper format (see Figure 1 for a typical load). The largest piece was one thickness of stripped explosive (I = 2250 taps) that covered nearly half of a cylindrical test specimen when the charge was wrapped around it ($-90° \leq \theta \leq 90°$). On top of this layer was glued a smaller piece of stripped explosive which extended from $-60° \leq \theta \leq 60°$, for instance, when the charge was wrapped around the test specimen.

---

*The ratio of strip spacing to strip width for this stripping format is critical (see Reference 6). If the ratio is too small or too large, the peak pressure experienced by the test fixture between and under the strips will be nonuniform. This stripping method also requires the use of an "attenuator" of foam neoprene between the explosive and the test fixture to prevent spalling caused by excessive peak overpressures. The relation between attenuator thickness and the strip spacing-to-width ratio is also critical. The spacing-to-width ratio, 4, for 0.1-inch width strip is about the optimum to produce the minimum average specific impulse with the maximum uniformity of peak pressure. A 0.25-inch thick foam neoprene attenuator was used for all these tests.

in this region as a result of the two layers I = 4500 taps. Other layers were added in this fashion until the peak specific impulse that was desired over the crown line ($\theta = 0^\circ$) was obtained. (All gluing was done with waterbase glue as the explosive is susceptible to organic solvent glues.) Where areas of I = 9000 taps or multiples thereof were desired, solid sheets of the 15-mil explosive could be used; Figure 8 shows the effect of three layers of SE in approximating a cosine load. Specific impulse, I, varies discontinuously with layering as a function of θ, but, for any given θ, I was a constant in the axial direction of the cylinder to be loaded.

In a typical test, the cylindrical test specimen to be tested was mounted in the holder (see Section II-C) which was in turn mounted on the ballistic pendulum as seen in Figure 6. A 0.25-inch thick foam neoprene attenuator was glued to the specimen surface as seen in Figure 9 (see footnote, page 13 for explanation), and the made-up layered explosive charge was wrapped around and glued to the outside of the neoprene layer such that it was symmetric about the crown line of the test cylinder. Running loads were obtained by initiating the SE charge with a blasting cap and a plane wave generator in one of the ways to be described. The peak load was determined from the number of layers of explosive on the crown line and the characteristic specific impulse per unit thickness of Detasheet D, or was calculated from the displacement of the ballistic pendulum.

SE charges were initiated in one of three ways. In each case, the initiation was accomplished with a plane wave generator consisting of one 15-mil thickness of sheet explosive cut into the pattern as seen in Figure 9 (which was initiated with an E106 blasting cap at the apex of the triangular area).

(1) A circumferential running load was obtained by gluing the ends of the plane wave generator along the crown line ($\theta = 0^\circ$) of the charge on the test fixture. This produced a load which initiates along the crown line and runs from $\theta = 0^\circ$ to $\pm 90^\circ$ circumferentially.

(2) A circumferential running load was obtained by gluing the ends of the strips of the plane wave generator along the $\theta = 90^\circ$ line of the charge on the test fixture. This produced a load which runs from $\theta = 90^\circ$ to -90° circumferentially.

(3) A longitudinal running load was obtained by gluing the ends of the strips of the plane wave generator at even spacing from $\theta = -90^\circ$ to 90° along one end of the cylinder.

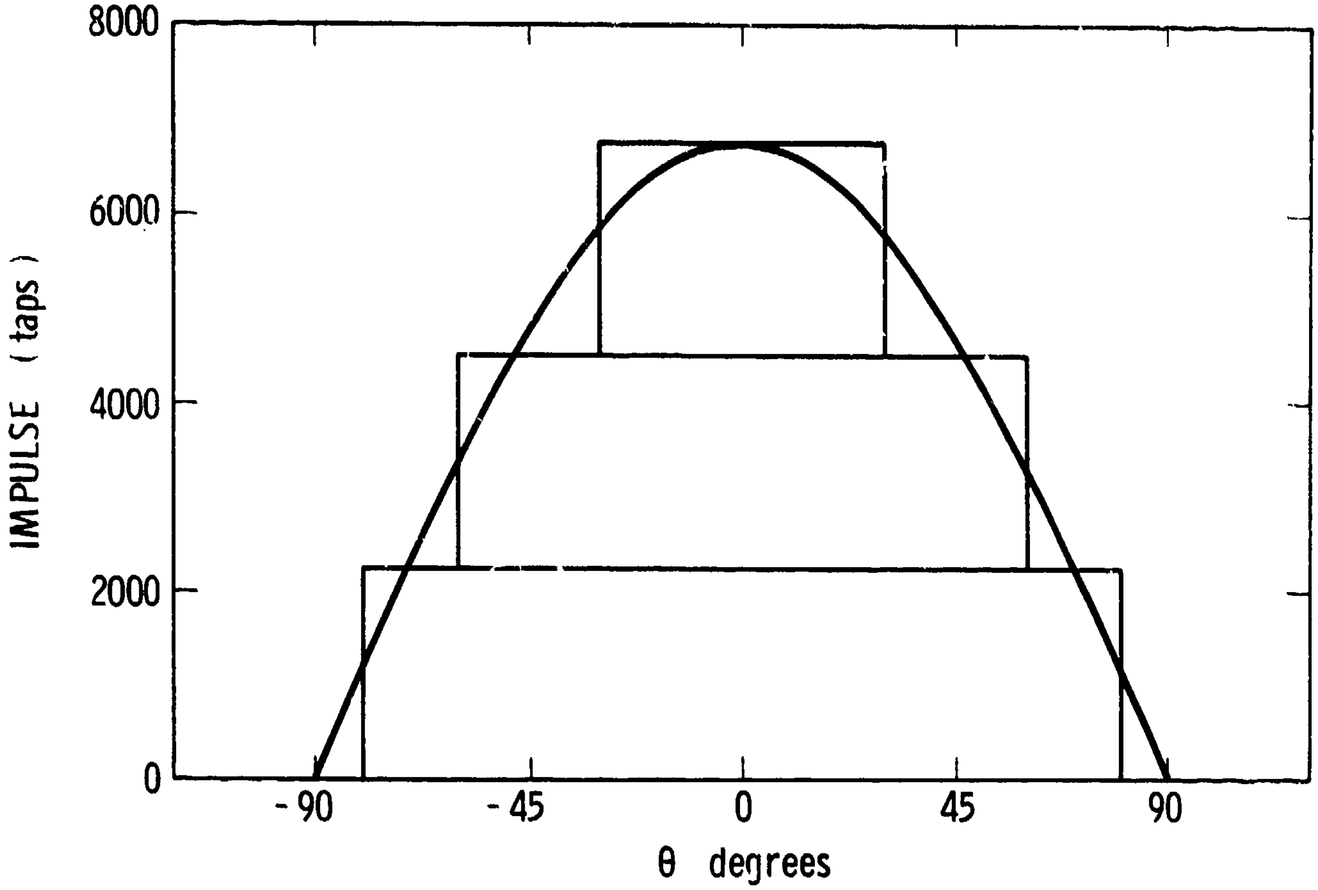

Figure 8. Cosine Load Approximated by Three Layers of Stripped SE. The cross-sectional area of the SE approximately equals the area under the cosine curve.

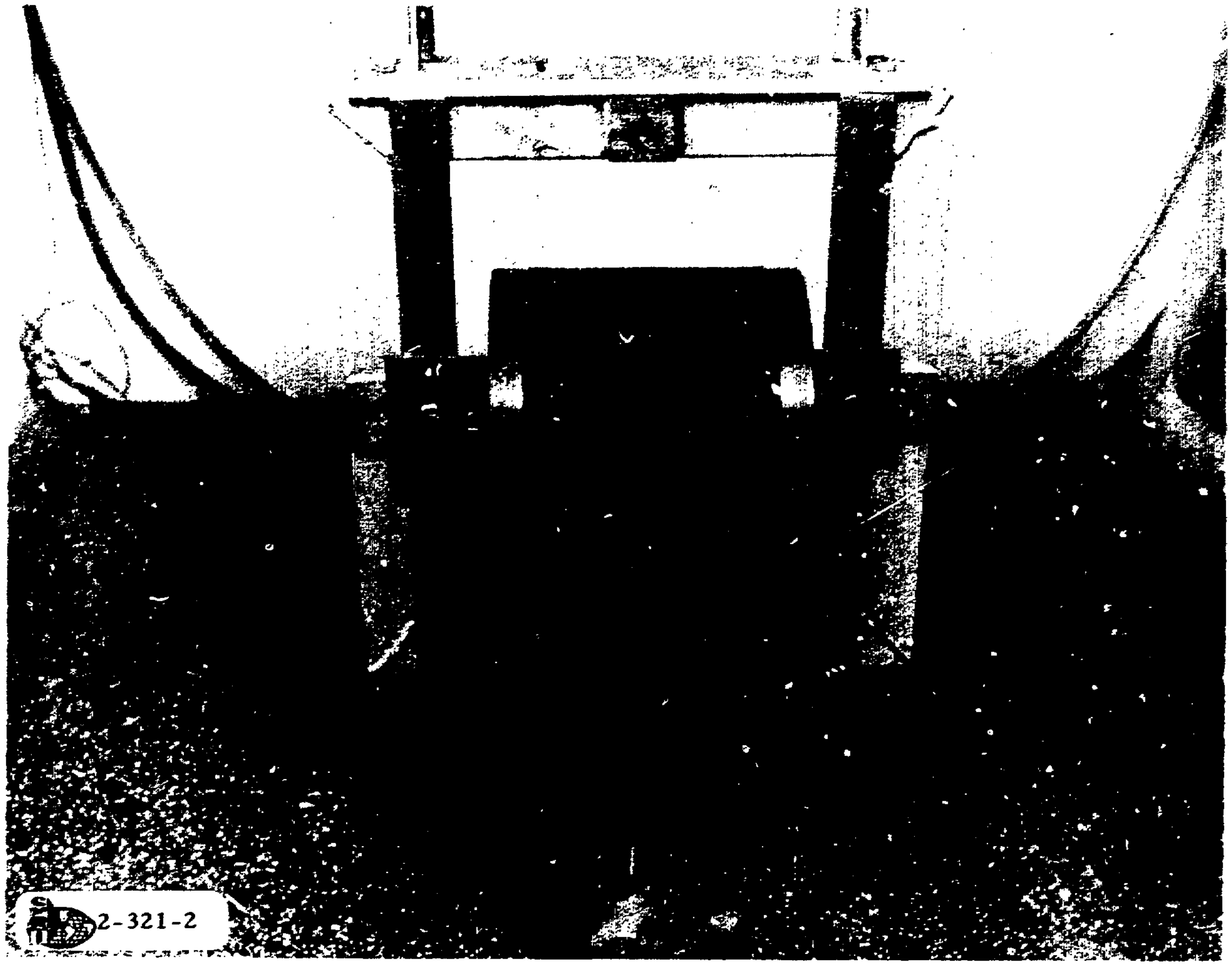

Figure 9a. Test Cylinder Mounted on Pendulum with Neoprene Layer in Place

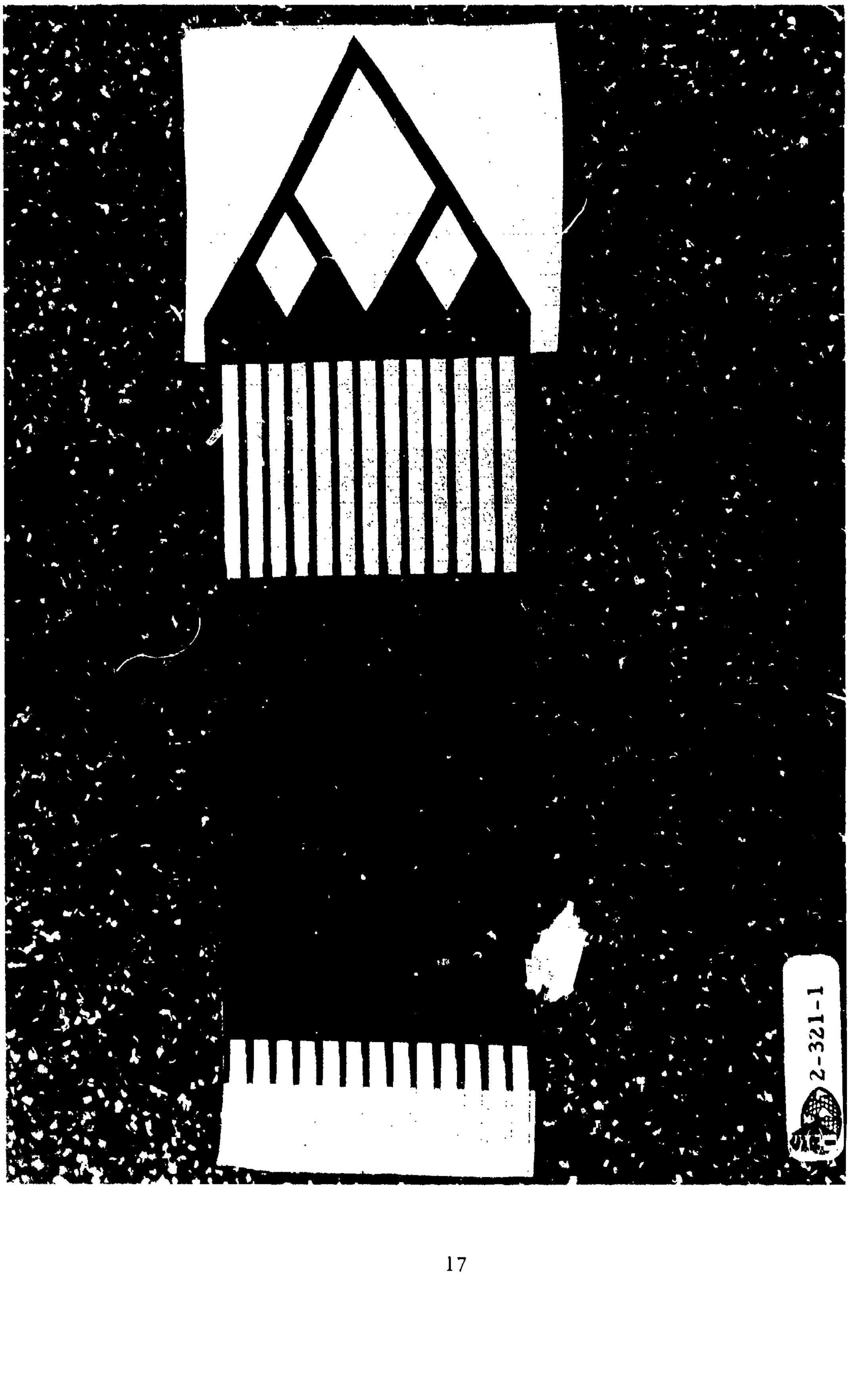

Figure 9b. Planewave Generator Pattern and SE Load

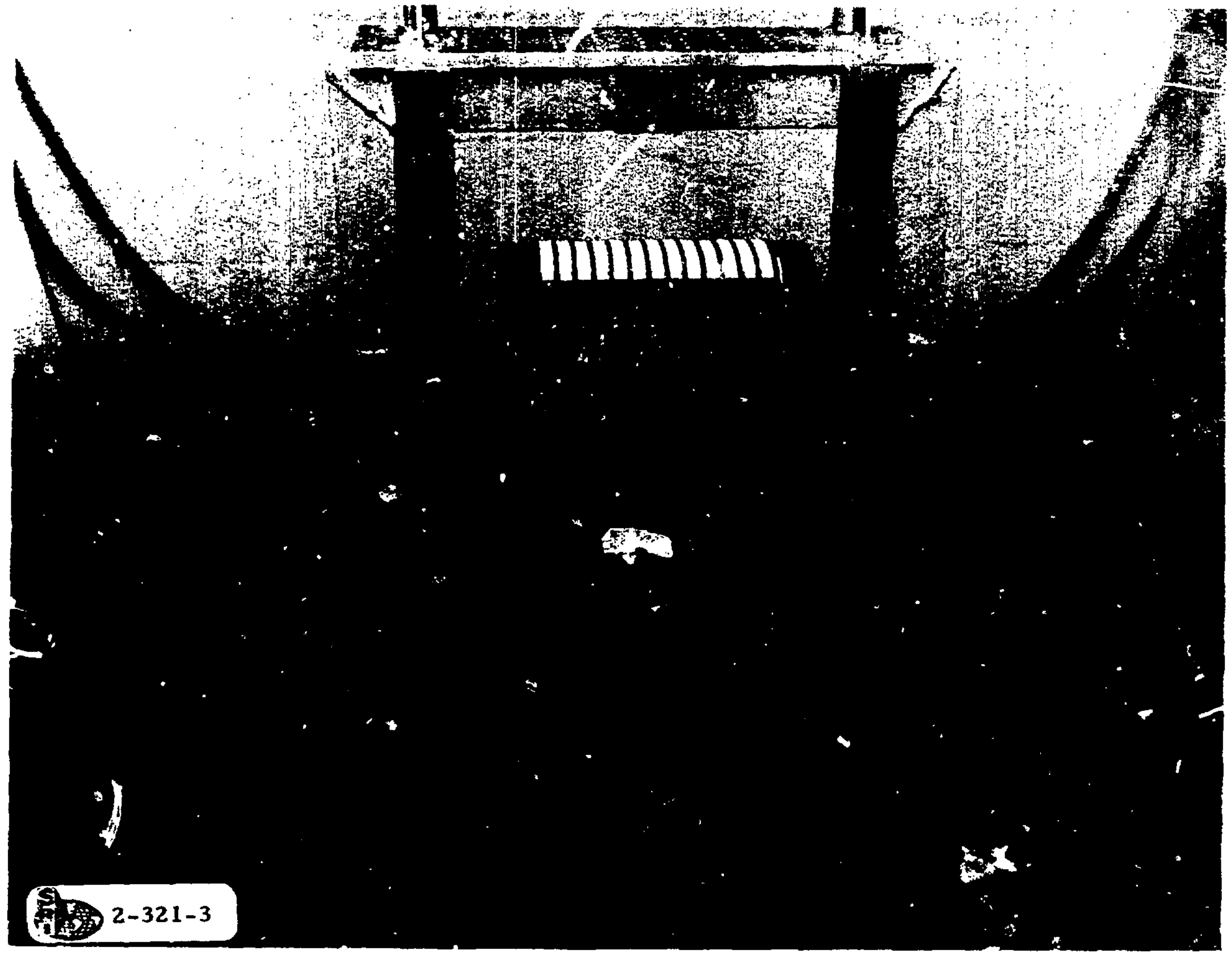

Figure 9c. Test Cylinder Mounted on Pendulum with Stripped and Layered SE Load in Place

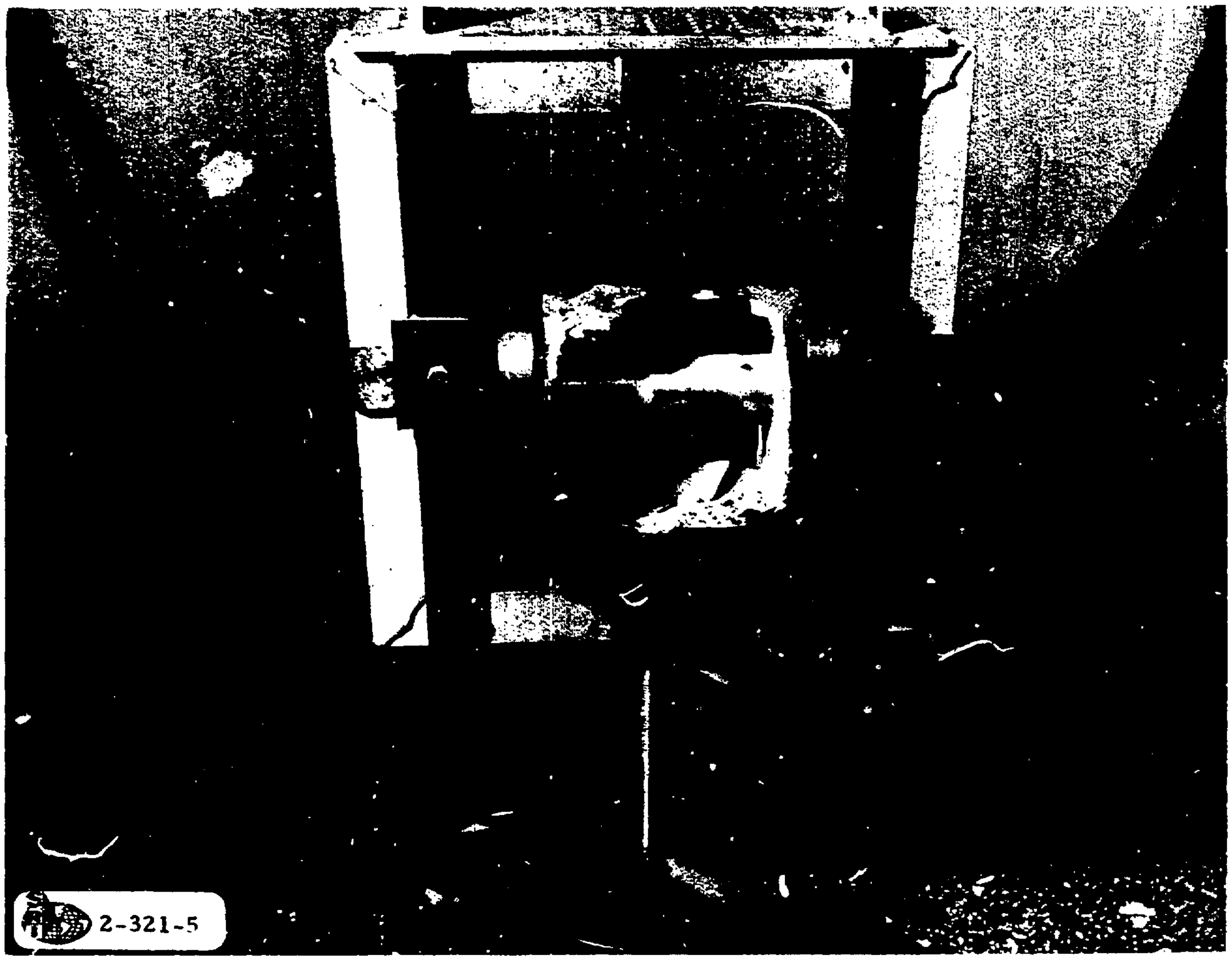

Figure 9d. Test Cylinder After Loading

Using this method, initiation would take place at numerous points along a semi-circumference of the cylindrical test fixture at one of its ends, and the load would run longitudinally in the axial direction of the cylinder for those areas where solid sheets of explosive were used in the charge.

b. SASN Initiated with SE

For one test, a running load was obtained with SASN by using SE as an initiator (instead of the usual light initiation of the SASN). In this test, a cylindrical test specimen was sprayed with SASN, as described in Section II-C-1a and mounted on the ballistic pendulum. A plastic tamper was hinged to the specimen holder, as described in Section II-C-1b. A 0.1-inch wide strip of 15-mil SE was glued onto the tamper such that, with the tamper in place, the strip ran up the crown line of the cylindrical test fixture. The strip was detonated at one end with an E106 blasting cap. Since the detonation velocity of SE is greater than that of SASN, the SASN was initiated by the SE along the crown line of the structure with a circumferentially running load at the rate of the SE detonation velocity.

D. Electronics Instrumentation

1. General

Two types of electronic instrumentation setups were used to perform these tests. We refer to these as "instrumented" and "non-instrumented" tests. In the former the test cylinders were strain-gaged at several locations, and dynamic wall displacement measurements were attempted (this instrumentation is described under "Cylinder Response Instrumentation" in the following section). For these tests, ballistic pendulum displacement data were also taken, from which the peak applied specific impulse could be calculated. For non-instrumented tests, only the ballistic pendulum data were taken. Each test is characterized as instrumented or non-instrumented in Table II, Section III, Test Results.

2. Ballistic Pendulum Instrumentation

An important step in the explosive loading of the test specimens was the determination of the peak specific impulse of the applied load. This was measured with the aid of a ballistic pendulum. Our ballistic pendulum was designed to have a period which was long with respect to the maximum load time. The total impulse in the direction of the pendulum displacement, I_x, is proportional to the pendulum displacement, δ (inches), and inversely proportional to the pendulum period, τ (secs).

$$I_x = \frac{2\pi M\delta}{\tau} \quad \text{(lb-sec)} \tag{2}$$

where M is the pendulum mass in slugs (see Reference 8).

This equation holds for a load that is applied at the center of percussion of the pendulum. The center of percussion of our compound pendulum, ℓ, was obtained from the equation

$$\ell = \frac{\tau^2 g}{4\pi^2} \quad \text{(inches)} \tag{3}$$

where τ = pendulum period in sec.

The pendulum had a natural period of 2.87 sec and a center of percussion of 80.4 inches from the suspension point without a counterweight. The same pendulum had a period of 2.9 sec and center of percussion of 82 inches with a 11.9 lb counterweight (see Figure 6). The centers of the test cylinders loaded in this project were 81 inches below the suspension point of the pendulum.

Since all of the cylinders on this project were loaded with a frontal-cosine load, the peak specific impulse, I_o, may be obtained by substituting Equation (2) into the equation (obtained by integrating the component of the specific impulse in the direction of the pendulum swing over the loaded area of the cylinder)

$$I_o = \frac{2I_x}{\pi RL} \tag{4}$$

where R is half the cylinder O.D. in inches, and L is the span length in inches. This results in the equation for small displacements

$$I_o = \frac{276\ M\delta}{\tau RL} \quad \text{(kilotaps)} \tag{5}$$

Values for I_o were calculated from Equation (5) from the pendulum displacement, δ, as measured during each test in the following fashion. The pendulum displacement was monitored at the point of suspension with a Rotary Variable Differential Transformer (RVDT). The RVDT was connected to the rotating axis of the pendulum and produced a voltage proportional to the angular position of the pendulum. The RVDT output was fed into an X-Y recorder as well as one channel of an Ampex FR-1900 tape recorder. Before and after each shot, the RVDT was calibrated manually by displacing the pendulum a small distance and noting the deflection of the pen on the X-Y recorder.

3. Cylinder Response Instrumentation

Some of the test cylinders loaded for these tests were instrumented with strain gages and displacement probes. Figure 10 shows the strain gage locations used for all such tests. The gages were Micro Measurements type EA-13-062TT-120 rosettes which were mounted on the cylinder crown line (internal cylinder wall) such that one gage was perpendicular and one gage was parallel to the crownline at each of three locations (L/4, L/2, 3L/4 for $\theta = 0^{\circ}$). The gages were mounted with Micro Measurement M-bond Adhesive Resin type AE-15 to minimize the premature debonding of a gage from the cylinder wall during the course of a test. The leads from each rosette were run perpendicular to the crownline, 180° around the cylinder, and were glued to the cylinder wall to minimize premature detachment of the leads during a test. With all of these precautions, however, the maximum strain measurable with these gages was 5%.

For a typical channel of strain measurement, one gage was used as the active element in a standard, one-arm bridge circuit. The output of the bridge circuit was impedance matched to the input of one channel of an Ampex FR-1900 tape recorder with wideband II FM electronics. Each channel was calibrated by paralleling the active strain gage prior to a test with a calibration resistor which produced a signal simulating a known value of strain. This calibration signal corresponds to a compressional strain and was recorded and used as a reference on playback.

An attempt was made to measure wall displacement on the crownline at two locations with the use of linear potentiometers. The linear pots were mounted such that their arms extended through holes in the 1.5-inch diameter specimen holder rod and could contact the cylinder wall at L/3 and 2L/3 (for $\theta = 0^{\circ}$). The pots were in a simple voltage divider circuit which was output to the tape recorder. This system suffers from several obvious drawbacks among which are the facts that it is a contacting system and that the inertia of the pot armatures can lead to overshoot. There was no feasible alternate system, however, to measure wall displacements over the required range under the existing blast test conditions for this geometry test specimen. Accordingly, this method was tried as a best technique for the circumstances.

All the cylinder response data taken during the course of a test were recorded on the Ampex FR-1900 tape recorder at 120 ips, with a maximum frequency response of 500 kHz. The data were replayed after each test at 1-7/8 ips into a CEC recording oscillograph to obtain the records which appear in Appendix B. The oscillograph galvos were frequency-limited at 2.5 kHz, which gives an overall system maximum frequency response of 160 kHz.

Figure 10a. Cylinder View Showing Placement of Strain Gages

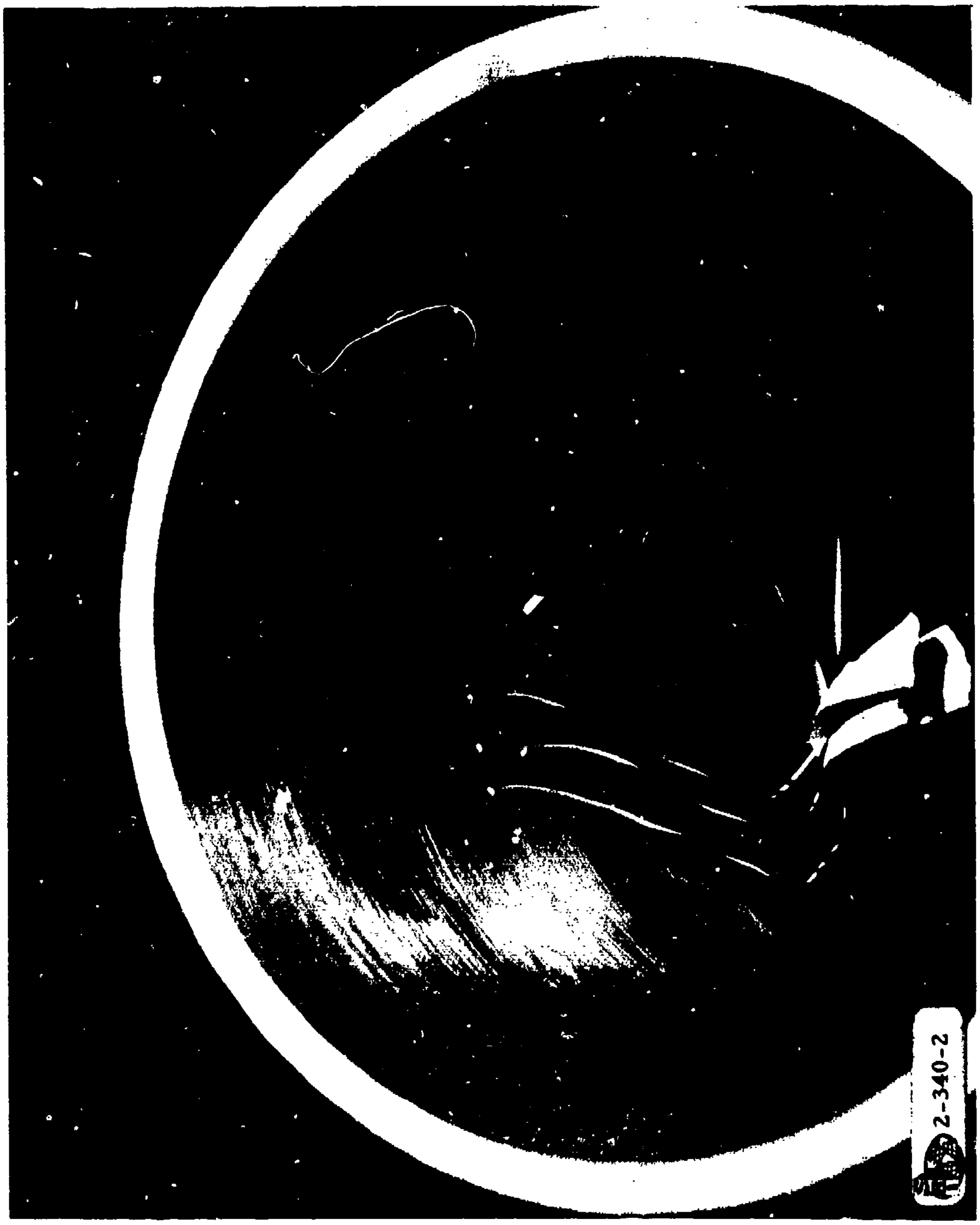

Figure 10b. Cylinder View Showing Strain Gage Leads

III. RESULTS

A. General

There were twenty-seven tests run on the specimens of various materials described in the previous section. These included some repeat tests on unbonded cylinders, for a given set of test conditions, to ensure that strain gage data were obtained when noise problems interfered with the data. Table II gives a synopsis of the test conditions and results for each test. Details on the cylinder material, explosive load, and initiation have been given in the previous section. The peak specific impulse levels and instrumentation results are discussed below. Column seven of the table gives a gross assessment of the damage level in terms of the minimum lethality criteria. The minimum lethality damage to a test specimen was assumed to occur when permanent deformations to the cylinder wall were of the order of the cylinder radius.(7) In cases where the test specimens suffered this level of damage (or greater), only crude measurements could be made of the peak wall deflections because of the overall deformation of the cylinders. Column seven of Table II shows a "plus" sign for those specimens which were obviously damaged in excess of the minimum lethal level, a "zero" for those specimens which were damaged very near the minimum level. Where it was possible to measure a value of the permanent deflection of the cylinder w .lls for less than minimum lethal damage, these values are given in column eight of Table II. The table also indicates if each shot was instrumented with strain gages and displacement probes.

Appendix A contains photographs of the cylinders tested. Generally, it can be seen that, for the heavier loads (18.0 kilotaps or greater) on phenolic bonded specimens (Tests 2 through 4, 6 and 7), the substrates came unbonded from the phenolic in the area of loading, and the phenolic fractured into small pieces which fell away from the cylinder. For Tests 8 through 10, phenolic bonded on lead substrates, the lead substrate came unbonded from the phenolic, and the phenolic was left almost intact except for some minor cracking. It will be noted in the photographs that the end elamping arrangement for these tests held the ends of the test specimens fixed so that, even after a test, the cylinder ends are parallel to one another. This rigid clamping of the cylinder ends occasioned tearing of the specimen substrate in the region of the clamping for the heavier loads on the phenolic bonded specimens; this was particularly true of the lead substrate specimens.

Since the maximum specific impulse level attainable for SASN by itself is about 10 kilotaps, it was evident from the data of shells 1 through 10 (using SE) that SASN by itself would not be sufficient to obtain minimum

TABLE II

TEST CONDITIONS AND RESULTS

Shell No.	Cylin. Matl.	Explo-sive	Type of Load	Init. (1)*	I_o (4) Peak Spec. Imp. (k-taps)	Min. Leth. Damage Level	Peak Final Dis-place-ment (in.)	Instr.
1	Al/Phen	SE	Run	D	9.0	-	0.1	No
2	"	"	"	D	27.0	+	---	No
3	"	"	"	D	18.0	0	---	No
4	"	"	"	B	18.0	0	---	No
5	"	"	"	B	15.7	-	1.78	No
6	"	"	"	D	18.0	+	---	Yes
7	"	"	"	B	18.0	0	---	Yes
8	Pb/Phen	"	"	B	15.7	+	---	No
9	"	"	"	B	11.2	0	---	No
10	"	"	"	B	9.0	-	0.92	Yes
11	Al/Phen	SASN-Tamp.	Sim	A	12.6	-	0.0	No
12	"	"	Run	C	19.2(2)	-	0.53	No
13	"	SE	"	E	15.7	-	1.35	Yes
16	Alum.	SASN	Sim	A	7.02	+	---	Yes
17	"	SE	Run	E	9.00	+	---	Yes
18	"	SASN	Sim	A	7.45	0	1.99	Yes
19	"	SE	Run	E	4.5(3)	-	0.94	Yes
20	Pb	"	"	E	4.5(3)	-	0.97	Yes
21	"	"	"	E	4.5	+	---	Yes
22	Alum	SASN	Sim	A	6.66	-	1.63	Yes
23	Pb	"	"	A	3.33	-	0.25	Yes
24	"	"	"	A	3.12	-	0.25	Yes
25	"	"	"	A	3.58	-	0.25	Yes
26	"	"	"	A	4.18	-	0.25	Yes
27	Alum	"	"	A	4.44	-	0.80	Yes
28	"	SE	Run	E	4.5	+	---	Yes
29	Pb	"	"	E	4.5	+	---	Yes

*Explanation for Notes (1), (2), (3) and (4) are given on the following page, indicated as Table II (continued) - Explanation of Notes.

TABLE II (continued)

EXPLANATION OF NOTES

Notes	Explanation
(1)	Types of Initiation (described in detail in Section II) A - Simultaneous initiation with a xenon lamp B - Longitudinal running load initiated with an SE plane-wave generator at one end of the cylinder C - Longitudinal running load using an SE strip on the crown line to initiate SASN D - Circumferential running load using an SE planewave generator fixed at $\theta = 90^\circ$ E - Circumferential running load using an SE planewave generator fixed at $\theta = 0^\circ$
(2)	This level is probably too high because SE was used to initiate the SASN
(3)	Poor ignition of SE.
(4)	The specific impulse levels for SASN tests were obtained from ballistic pendulum data as described in Section II. D. 2. The specific impulse levels for SE tests were obtained from the calibration factor for SE given in Section II. C. 2. In general, ballistic pendulum data for SE tests did not compare well with impulse values obtained from the SE calibration factor because the test structures were so grossly damaged that "long time" effects such as jetting of explosive gases from the detonated SE affected the pendulum displacement.

lethality damage levels for the phenolic-bonded cylinders. Accordingly, the tamped SASN technique was tried in Test 11, and tamped SASN with SE initiating strip was tried for Test 12. Neither of these tests produced minimum lethality damage.

Subsequent testing was performed on 1 x 10-inch flat areas covered with various combinations of explosive to find a combination of SASN and SE or sprayed PETN powder in a binder that could be simultaneously initiated and would produce sufficiently high specific impulse levels to produce the desired damage in the phenolic-bonded Al cylinders. We were unable to initiate SE with SASN or SASN-PETN. PETN powder in a carbon tetrachloride-Elvax solution was sprayed on a Mylar coupon, allowed to dry, and sandwiched remotely with an equal sized plexiglas coupon on which a layer of SASN had been deposited. This "tamped SASN-PETN" was detonable with the xenon light source, but the simultaneity of detonation was degraded below an acceptable level for the semi-cylindrical area we were contemplating loading. Consequently, efforts were abandoned to load the phenolic-bonded cylinder to minimum lethality levels of damage with a simultaneously initiated load. Test 13 was an instrumented SE load with circumferential running initiation and Test cylinders 14 and 15 have been left for subsequent testing.

For the tests made on bare substrates (Tests 16 through 29), minimum lethality damage was easily obtained with SASN. The specific impulse levels where this damage occurred, however (around 4.5 to 7.5 kilotaps), were difficult to obtain with SE while still maintaining a reasonable facsimile of cosine loading. This is due to the fact that 4.5 kilotaps represent a stripped SE load of a thickness of only two, 15-mil layers of explosive. It should be pointed out that less than a 15-mil of thickness of Detasheet D will not detonate with consistency.

Appendix B contains the data obtained from the instrumented shots. Specific comments about these data are given in the following sections.

B. Specific Impulse Measurements

1. SE

Peak specific impulse data were calculated from the ballistic pendulum displacements for each of the tests which used SE loads. Peak specific impulse data were also obtained for these tests from the explosive characteristic specific impulse per unit thickness and the known thickness of SE used on each test. For a test setup such as ours, where foam neoprene was used between the SE and the loaded surface, the constant for Detasheet D is 600 kilotaps/mil.[6,8] Even multiples of 15-mil

thicknesses of SE were used, but the specific impulse of a single layer could be reduced to one-fourth that of a 15-mil thickness using the stripping technique previously described. Thus, using the constant for SE, the peak specific impulse levels are multiples of 2250 taps.

The peak specific impulse levels as calculated from the pendulum displacement data were erratic (see Table III). The ballistic pendulum data tended to give higher values than expected, especially for the lighter loads. A number of reasons can be given to account for the discrepancies. The most prominent reason was the existence of the plane wave initiators. The initiators consisted of several grams of SE (approximately 6 to 8). They could not be positioned such that they would work effectively as an initiator and yet be distant enough not to affect the ballistic pendulum displacement. The blastwave emanating from this explosive could in fact affect the pendulum displacement, causing too great or too little displacement, depending on complicated factors of blastwave reflection. Most of our tests were run in an enclosed test cell. The impulse from blastwaves reflected off the cell walls could also affect the ballistic pendulum displacement, especially blastwaves emanating from a high-energy density explosive such as SE. Furthermore, for loads which were sufficient to "punch" a hole of significant size in the test specimens, a jetting effect could occur from trapped explosive gases.

Because a reasonably accepted value for specific impulse per unit thickness is known for Detasheet D, and because we felt our ballistic pendulum data were unreliable for the reasons stated above, the values given in Table III for peak specific impulse for all our SE tests are based on the 600 taps per mil constant and the maximum thickness of SE used on each test.

2. <u>SASN</u>

The peak specific impulse values for the SASN loaded tests were calculated from the pendulum displacements using the equations given in Section II-D-2. For the SASN tests, initiation was accomplished with the xenon lamps, and there was no error in the pendulum displacement measurement (as in the case of the SE) because of the initiation technique. Tests run with the xenon lamps in place but no SASN on the test fixture showed that even when the lamps exploded as a result of the energy dumped through them from the capacitor bank (see Section II-C-1 for the system description) there was no significant displacement of the ballistic pendulum. The tests run with SASN loading were at peak tap levels below 10 kilotaps (i.e., relatively low peak tap levels) because of the maximum limit of SASN that can be made to adhere to a test fixture in the spray operation. Ballistic pendulum data for these tests

TABLE III

PEAK SPECIFIC IMPULSE DATA FOR SE

Test Number	Pendulum Value (kilotaps)	SE Value (kilotaps)
1	2.9	9.0
2	23.4	27.0
3	15.1	18.0
4	16.9	18.0
5	12.5	15.7
6	23.9	18.0
7	24.8	18.0
8	23.1	15.7
9	11.5	11.2
10	6.31	9.0
13	23.6	15.7
17	13.8	9.0
19	7.11	4.5
20	4.01	4.5
21	7.7	4.5
28	13.5	4.5
29	13.8	4.5

at the lower loading levels were thus more consistent because the effect of reflected airblast waves off the test cell walls would be considerably less.

C. Damage Assessment

As is evident from the photographs of the test cylinders after loading (Appendix A), for the most part, damage levels were too great to make profiling of the cylinder wall after testing a feasible procedure for all tests. Accordingly, the following descriptions cover in a qualitative way (and where possible in a quantitative way) an assessment of damage levels for each test. Other details of each test appear in Table II.

Test 1 - Threshold damage was obtained as a result of this loading. Profiling of the internal circumference of the substrate at several points above the cylinder base with a dial indicator showed a maximum displacement of the substrate of 0.1 inch. Because this damage level was so minimal, we used this test specimen for Test 2, loading along a crown line on the opposite side of the cylinder.

Test 2 - The phenolic layer fragmented away over an area 5.25 x 0.50 inches symmetric about the crown line. The substrate cylinder wall tore in two pieces and displaced 6.0 inches in some places and tore along both clamp edges from $\theta = -60^\circ$ to 60°. This damage was far in excess of minimum lethality.

Test 3 - The phenolic layer fragmented away under an area 5.25 x 5.50 inches symmetric about the crown line. The substrate cylinder wall displaced from 0.25 to 3.5 inches through a line of maximum displacement ($\theta = 20^\circ$). This damage is very close to minimum lethality.

Test 4 - The phenolic layer fragmented away under an area 5.25 x 4.75 inches symmetric about the crown line. The substrate displaced from 1.25 to 3.00 inches near the crown line. This damage would be very close to minimum lethality.

Test 5 - The phenolic layer became cracked and some of the upper layers fragmented away over an area of 5.25 x 4.5 inches. The substrate displaced from 0.0 to 1.78 inches along the crown line. The substrate tore slightly at the top clamp edge ($\theta = 5^\circ$ to 10°) and at a height of 2.75 inches above the base from $\theta = -45^\circ$ to $+45^\circ$. This damage is assessed as less than lethal damage.

Test 6 - The phenolic fragmented away over an area of 5.25 x 3.5 inches symmetric about the crown line. The substrate displaced approximately 2.5 inches along the crown line and tore at both end clamps from

θ = -70° to $+70^{\circ}$. This damage was slightly greater than minimum lethality.

Test 7 - The phenolic fragmented away over an area of 5.25 x 5.25 inches. The substrate displaced approximately 2.5 inches along the crown line, tearing at the end clamps from θ = -65° to $+60^{\circ}$. This damage was very close to minimum lethality.

Test 8 - The phenolic remained practically intact for this test. The substrate became debonded from the phenolic over the span length from $\theta = -70^{\circ}$ to $+70^{\circ}$ and displaced 3.0 inches or more at some points. This damage would be considered greater than minimum lethality.

Test 9 - The phenolic remained intact for this test. The substrate became debonded from the phenolic over the span length from $\theta = -70^{\circ}$ to $+55^{\circ}$ and displaced approximately 2.5 inches at its maximum. This damage would be considered very close to the minimum lethality damage.

Test 10 - The phenolic remained intact for this test. The substrate became debonded from the phenolic from $\theta = -40^{\circ}$ to $+40^{\circ}$ and displaced a maximum of 0.92 inch along the crown line. This damage is considerably less than minimum lethality.

Test 11 - This test cylinder was virtually undamaged (no measurable substrate deformation). Some cracking of the phenolic occurred at the end clamps because of the clamp compression.

Test 12 - Some cracking of the phenolic occurred in this test as well as debonding of the substrate over the span length from $\theta = -30^{\circ}$ to $+30^{\circ}$. There was a maximum displacement of the cylinder wall of about 0.53 inch but no tearing of the substrate anywhere. This damage is much less than minimum lethality.

Test 13 - The phenolic cracked and fragmented over an area 5.25 x 6.00 inches symmetric about the crown line. The substrate deformed over the span length from $\theta = -50^{\circ}$ to $+50^{\circ}$ with a maximum displacement along the crown line of 1.35 inches.

Test 16 - The test cylinder deformed over the span length from $\theta = -90^{\circ}$ to $+90^{\circ}$ displacing approximately 2.5 inches at the maximum. This displacement could have been larger but was restricted by the contacting displacement probes. The cylinder ends pulled loose of the clamps, allowing some axial bending. This damage would be considered greater than minimum lethality.

Test 17 - The test cylinder tore axially at approximately the crown line and circumferentially at the base clamp for $\theta = -70^{\circ}$ to -30° to $+90^{\circ}$. It appears not to have torn at the top clamp because it pulled loose. The maximum wall displacement was almost equal to the cylinder diameter in some places; thus, the damage exceeded minimum lethality substantially.

Test 18 - This test cylinder did not tear, although it pulled loose from the top clamp slightly. The cylinder wall displaced from $\theta = -90^{\circ}$ to $+90^{\circ}$, about 1.99 inches at the maximum. The damage is at the minimum lethality level.

Test 19 - This cylinder deformed non-uniformly over the span length from $\theta = -75^{\circ}$ to $+70^{\circ}$. Maximum displacement occurred at several points up to 0.94 inch. The SE load for this test did not detonate completely, accounting for the fact that maximum wall displacement did not necessarily occur on the crown line. Because of the poor detonation, this test should be considered void.

Test 20 - The cylinder wall tore along the bottom clamp for this test and the detonation of the SE load was not complete. Maximum wall displacement was less than 0.97 inch.

Test 21 - Tearing of the cylinder wall occurred along the top clamp for this test. Maximum wall displacement was about 2.5 inches. This would be minimum lethal damage or greater.

Test 22 - The test cylinder wall deformed over the span length from $\theta = -70^{\circ}$ to $+70^{\circ}$ with a maximum displacement of about 1.63 inches. The cylinder appears to have pulled loose of the top clamp slightly but did not tear.

Tests 23 through 26 - The test cylinder walls for these tests displaced less than 0.25 inch at the maximum and were thus damaged less than minimum lethality.

Test 27 - The cylinder wall for this test deformed from $\theta = -70^{\circ}$ to $+50^{\circ}$ over the span length with a maximum displacement at $\theta = +20^{\circ}$ of about 0.80 inch or less than mimimum lethality damage.

Test 28 - The cylinder deformed from $\theta = -90^{\circ}$ to $+90^{\circ}$ over the span length. There was some tearing at the bottom clamp from $\theta = -40^{\circ}$ to $+30^{\circ}$. Wall displacements up to 3.00 inches occurred. This would be a damage level above minimum lethality.

Test 29 - The cylinder wall tore at the bottom clamp for this test from $\theta = -50^{\circ}$ to $+90^{\circ}$. The wall displaced at some points greater than 3.5 inches. This is greater than minimum lethality damage.

D. Instrumentation Results

1. Strain Gage Data

The strain gage data for instrumented tests are given in Appendix B. These data were obtained in the manner described in Section II-D-2 for those tests which have been indicated as instrumented tests in Table III. Serious noise problems were encountered for instrumented tests using SASN loads because of the high voltage (and high current) involved in the xenon lamp flashing process. This noise problem masked the strain gage data completely for some tests (notably Tests 16 and 18) and caused a short duration (less than 2 μsec) spike at the beginning of most of the SASN load tests, even after careful shielding and grounding. The data from Test 17 were lost because of an electronics malfunction. For those tests which produced strain gage data, the maximum measurable strain limit for the gages (5 to 6%) was usually reached within a short elapse time (0.3 msec) after the onset of the structural loading. At this point, the gages failed and the remaining parts of the record were noise.

2. Displacement Probe Data

No displacement probe data are shown in Appendix B because these data have to be considered unreliable. It was not possible to use non-contacting displacement probes for the expected maximum wall displacements for these tests because the displacements exceeded their maximum range, and the mechanically actuated contact displacement probes which we used suffered from overshoot or outright failure to operate in the blast environment. The nature of the tests precluded optical displacement measurements.

E. Discussion

The results of these tests provide an estimate of the peak specific impulse load for a cosine loading distribution which will produce minimum lethality damage to the various types of cylinders. The results also show some differences in the required load depending on the loading characteristics (i.e., simultaneous or running load). In addition, strain gage data have been obtained for a number of loading situations and types of test cylinders. The following observations should be made, however, about the problems encountered during this testing.

(1) The results showed that if the ends of the cylinders were held fixed throughout the course of a test, then tearing of the cylinder wall circumferentially near the end clamps would almost always occur for minimum lethality loading. This was especially true of the lead cylinders or where lead was used as the substrate.

(2) For low peak tap level loads of SE (i.e., 4.5 kilotaps), the thin layers of SE could not always be counted on to detonate completely.

(3) For the bare lead test cylinders, it was not possible to reduce the SE loads sufficiently to avoid damage in excess of minimum lethality while still expecting complete detonation of the SE and a reasonable approximation of a cosine load.

(4) For the test cylinders of phenolic bonded onto an aluminum substrate, it was not possible to obtain sufficiently intense simultaneous loading either through SASN or tamped SASN to produce minimum lethality damage, nor were alternative methods (in particular, a PETN-SASN combination) effective in terms of retaining the simultaneous initiation characteristic while increasing the peak specific tap level possible.

IV. CONCLUSIONS AND SUMMARY

A. Conclusions

1. Phenolic Bonded Aluminum Test Cylinder

The following conclusions can be reached about the phenolic bonded aluminum test cylinders loaded in this program. When the test cylinders were loaded with SE and initiated with a longitudinal running load (i.e., from $\theta = -90^\circ$ to $+90^\circ$ at $h = 0$), minimum lethality damage levels were obtained for a peak specific impulse of 18 kilotaps (as shown in Table II, Tests 4, 5, and 7). When these test cylinders were loaded with SE and initiated with a circumferential running load, from $\theta = +90^\circ$ to -90° (i.e., initiated along the line $\theta = +90^\circ$), lethality damage levels were also obtained for an 18 kilotap peak specific impulse (see Table II, Tests 1, 2, 3, and 6). When these test cylinders were loaded with SE and initiated with a circumferential running load with the line of initiation along the crown line $\theta = 0^\circ$, a load with a peak specific impulse of 15.7 kilotaps failed to produce lethality damage, although it did produce significant damage (see Table II, Test 13). It is inferred from these data that 18 kilotaps is approximately the peak specific impulse for the frontal cosine impulsive load necessary to produce minimum lethality damage for these test cylinders (with a running load) and that this level is not greatly affected by the method of initiation.

For all cases where minimum lethality damage levels occurred in the phenolic bonded aluminum cylinders, the phenolic material fragmented away under most of the area loaded (usually $\theta = -60^\circ$ to $+60^\circ$) and thus it could be said that the substrate came unbonded from the phenolic. For lighter loads (i.e., peak specific tap level less than 18 kilotaps), the substrate was debonded from the phenolic where damage occurred even when the phenolic remained essentially intact. For cylinders where lethality levels of damage or greater occurred, the aluminum substrates tore along or near the clamp edges, although the cylinder ends remained fixed.

A comparison between simultaneous and running loads for the phenolic bonded cylinders could not be made because the required specific impulse levels for lethality were much too high for SASN by itself, and other techniques using SASN either lacked the appropriate simultaneity or could not provide sufficient loading. Tests 1 and 11 showed that a tamped SASN load with a peak specific impulse of 12.6 kilotaps was not sufficient to produce measurable damage, while an SE circumferential running load of 9 kilotaps peak produced threshold damage. This indicates that a higher tap level is required for SASN loading to obtain the same level of damage as an SE load.

2. Loading of Phenolic Bonded Lead Test Cylinders

A peak specific level of 11.2 kilotaps produced minimum lethality damage levels in the phenolic bonded lead cylinders (see Table II, Tests 8, 9, and 10) for running SE loads initiated longitudinally. At the load levels used (15.7 kilotaps or less), there was apparently no damage to the phenolic material. The lead substrate became debonded from the phenolic over the damaged area, in all of the tests, and tore along the clamped ends for the lethality level loads and greater, when the cylinder ends remained fixed. Because of a limited number of test structures, the phenolic bonded lead cylinders were only tested with the longitudinal running loads.

3. Loading of Bare Aluminum Test Cylinders

The tests on the bare aluminum substrates offer a good comparison of the effect of simultaneous and running loads in producing damage on cylindrical shell specimens. When these test cylinders were loaded with SASN and simultaneously initiated, a peak specific level of 7.45 kilotaps was required to produce very close to lethality damage (see Table II, Tests 27, 22, 18, and 16). Actually the 7.45-kilotap level produced damage which could be interpreted as slightly less than lethality for Test 18.

When this same structure was loaded with SE at only the 4.5 kilotap peak specific tap level, however, with a circumferential running load initiated along the crown line $\theta = 0^\circ$, greater than lethality damage was produced when the SE detonated completely (see Table II, Tests 19, 28, and 17).

4. Loading of Bare Lead Test Cylinders

The loading of the bare lead test cylinders with SE indicated that lethality levels are obtainable for these structures for peak specific tap levels of less than 4.5 kilotaps (running initiation at $\theta = 0^\circ$). Of the three tests made (see Table II, Tests 20, 21, and 29) in which total detonation of the applied SE occurred, the structures were damaged beyond the minimum lethality level. Peak levels less than 4.5 kilotaps are not feasible with the stripped SE technique because cosine loading cannot be properly simulated with so few layers of the SE. Loading these bare lead

substrates with simultaneous initiated SASN of up to 4.18 kilotaps, however, produced only minimum or threshold damage to the structures (see Table II, Tests 23 through 26). These data show that a higher peak level would be required for the SASN loads to produce the same damage level as the SE.

B. Summary

The test data obtained by loading these cylindrical test structures show the following:

- A peak specific impulse of 18 kilotaps produces lethality damage in the aluminum phenolic specimens for the three types of SE running loads.
- A peak specific impulse of 11.2 kilotaps produces a minimum lethality damage in the lead/phenolic specimens for an SE longitudinally running load.
- A peak specific impulse of 7.45 kilotaps produces a minimum lethality damage in the aluminum specimens for a SASN simultaneous load. A load of peak specific impulse less than 4.5 kilotaps produces the same damage level for an SE circumferentially running load initiated along the crown line.
- Peak specific impulse loading less than 4.5 kilotaps produces lethality damage in the lead specimens for circumferential running SE initiated along the crown line. A loading greater than 4.18 kilotaps would be required to produce the same damage with SASN and simultaneous initiation.
- SASN or tamped SASN loads were not of a sufficiently high peak impulse level to produce lethality damage in aluminum/phenolic specimens.

Generally it can be said that at a 4.5 kilotap peak specific impulse level, the stripping and layering technique gives an altogether cruder approximation of cosine loading than does the SASN spray depositing technique. On the other hand, simultaneous loads for peak tap levels greater than 10 kilotaps are difficult to obtain with SASN, even when it is tamped. The evidence from the tests on the bare cylindrical shells indicates, moreover, that SASN loads with simultaneous initiation produce less damage than SE circumferential running loads for the same applied peak specific impulse levels.

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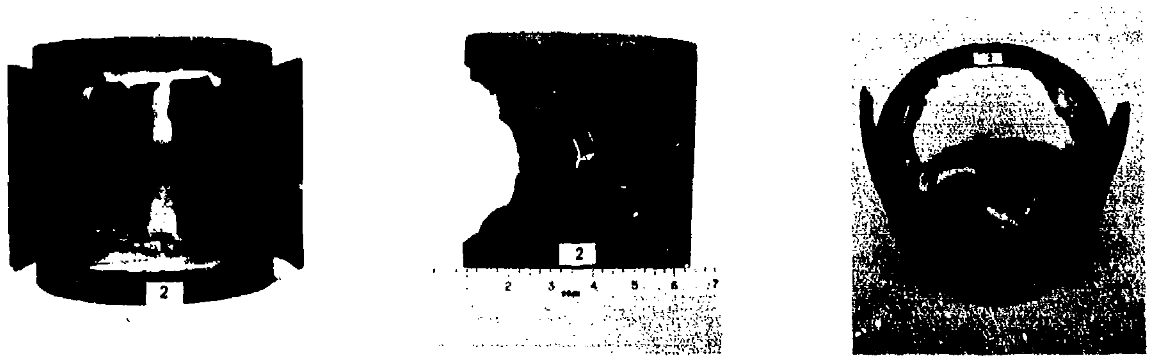
BRL CONTRACT REPORT NO. 232 in printing.

APPENDIX A

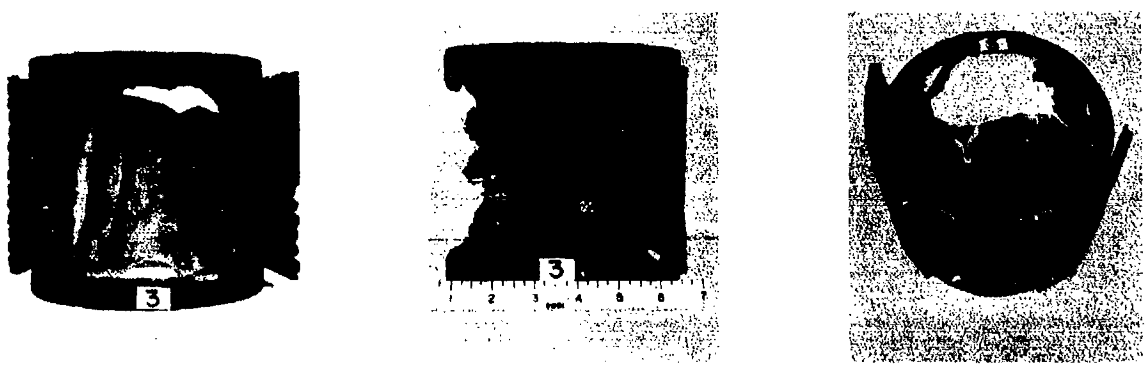
Photographs of Test Cylinders
After Loading

FRONT SIDE TOP



ALUMINUM/PHENOLIC CYLINDER

TESTS 1 AND 2 - DAMAGE PRODUCED BY SE LOAD OF 27 KILOTAPS



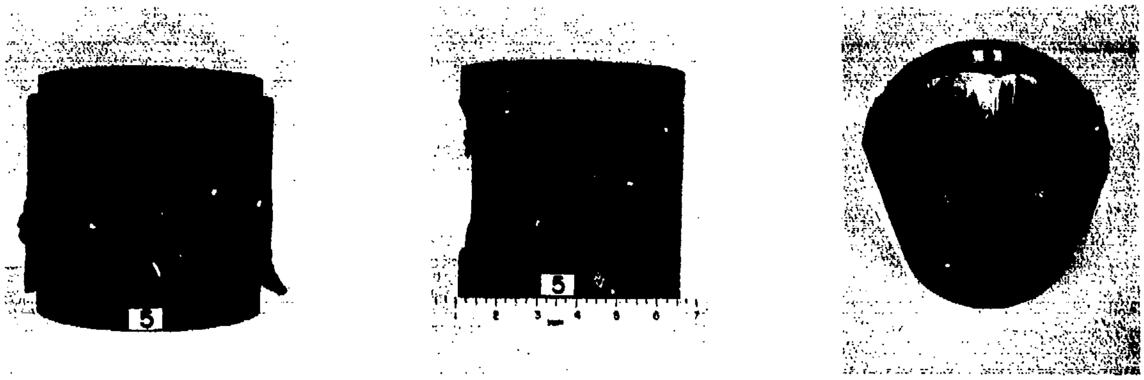
ALUMINUM / PHENOLIC CYLINDER

TEST 3 - DAMAGE PRODUCED BY SE LOAD OF 18 KILOTAPS

ALUMINUM/PHENOLIC CYLINDER

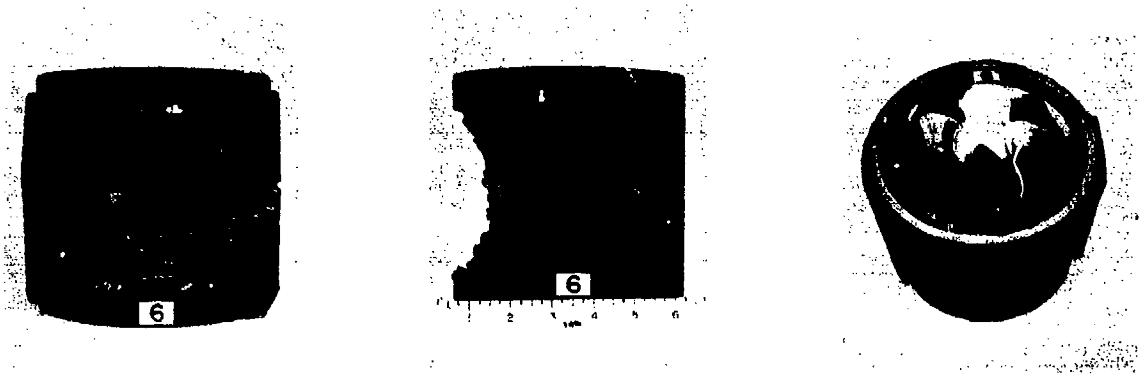
TEST 4 - DAMAGE PRODUCED BY SE LOAD OF 18 KILOTAPS

FRONT SIDE TOP



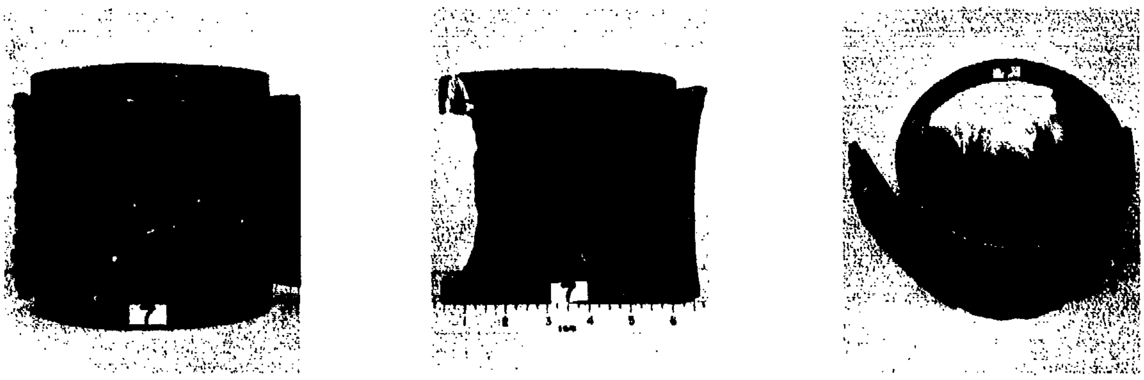
ALUMINUM/PHENOLIC CYLINDER

TEST 5 - DAMAGE PRODUCED BY SE LOAD OF 15.7 KILOTAPS



ALUMINUM/PHENOLIC CYLINDER

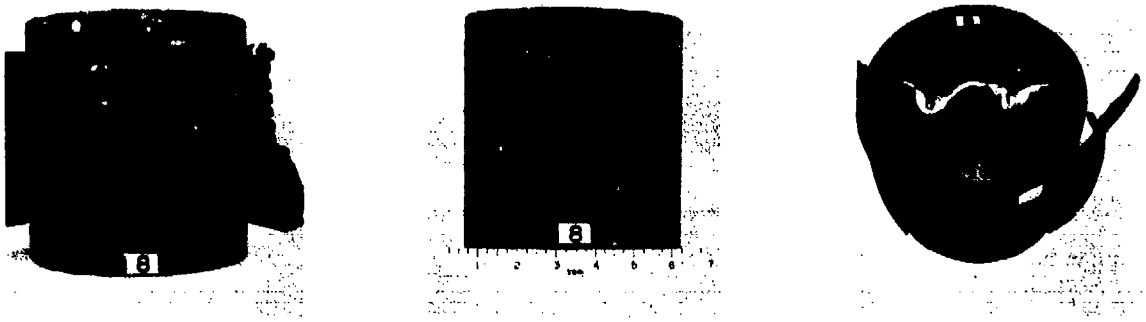
TEST 6 - DAMAGE PRODUCED BY SE LOAD OF 18.0 KILOTAPS



ALUMINUM/PHENOLIC CYLINDER

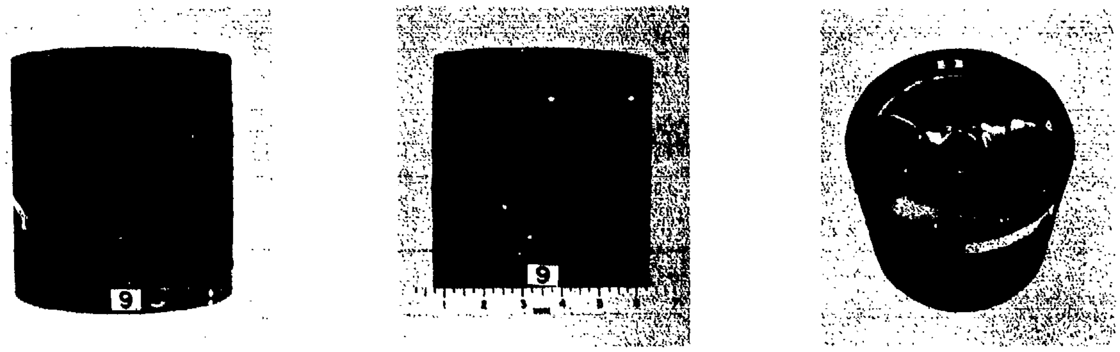
TEST 7 - DAMAGE PRODUCED BY SE LOAD OF 18.0 KILOTAPS

FRONT SIDE TOP



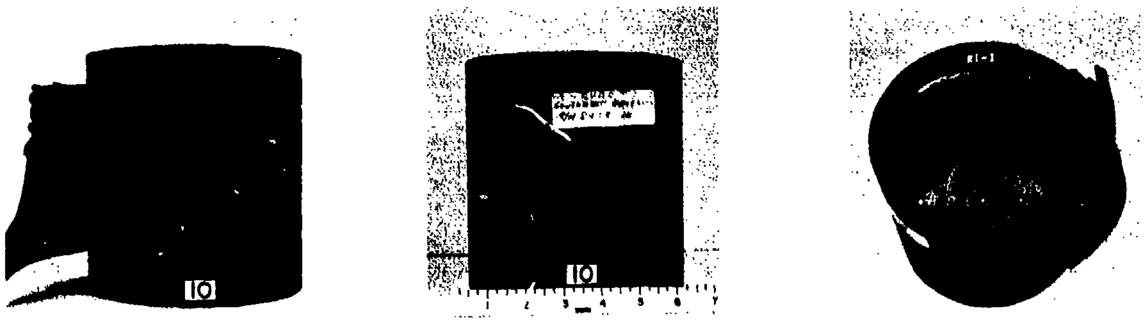
LEAD/PHENOLIC CYLINDER

TEST 8 - DAMAGE PRODUCED BY SE LOAD OF 15.7 KILOTAPS



LEAD/PHENOLIC CYLINDER

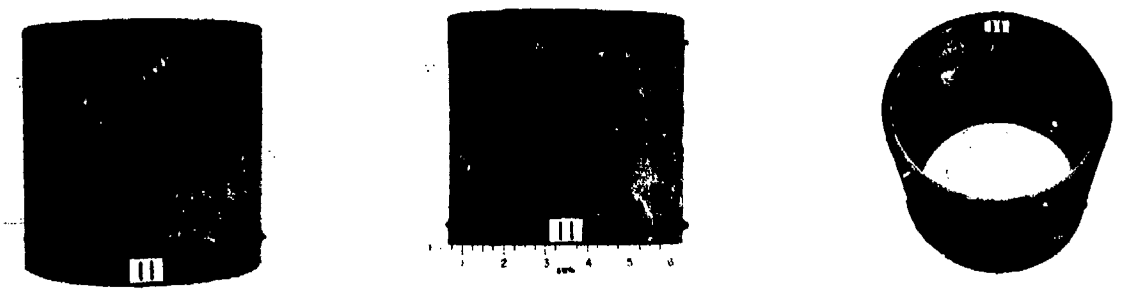
TEST 9 - DAMAGE PRODUCED BY SE LOAD OF 11.2 KILOTAPS



LEAD/PHENOLIC CYLINDER

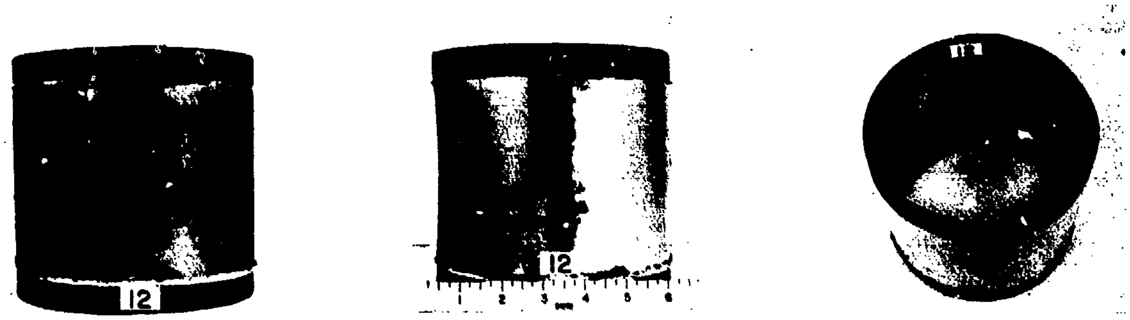
TEST 10 - DAMAGE PRODUCED BY SE LOAD OF 9.0 KILOTAPS

FRONT SIDE TOP



ALUMINUM/PHENOLIC CYLINDER

TEST 11 - DAMAGE PRODUCED BY A TAMPED SASN LOAD OF 12.6 KILOTAPS



ALUMINUM/PHENOLIC CYLINDER

TEST 12 - DAMAGE PRODUCED BY A SASN/SE LOAD

ALUMINUM/PHENOLIC CYLINDER

TEST 13 - DAMAGE PRODUCED BY AN SE LOAD OF 15.7 KILOTAPS

FRONT SIDE TOP

ALUMINUM CYLINDER

TEST 16 - DAMAGE PRODUCED BY SASN LOAD OF 7.02 KILOTAPS

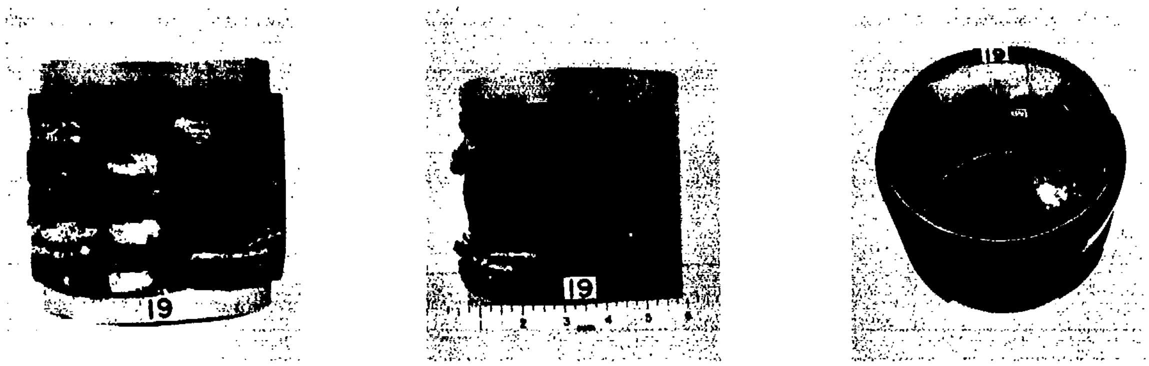
ALUMINUM CYLINDER

TEST 17 - DAMAGE PRODUCED BY AN SE LOAD OF 9.00 KILOTAPS

ALUMINUM CYLINDER

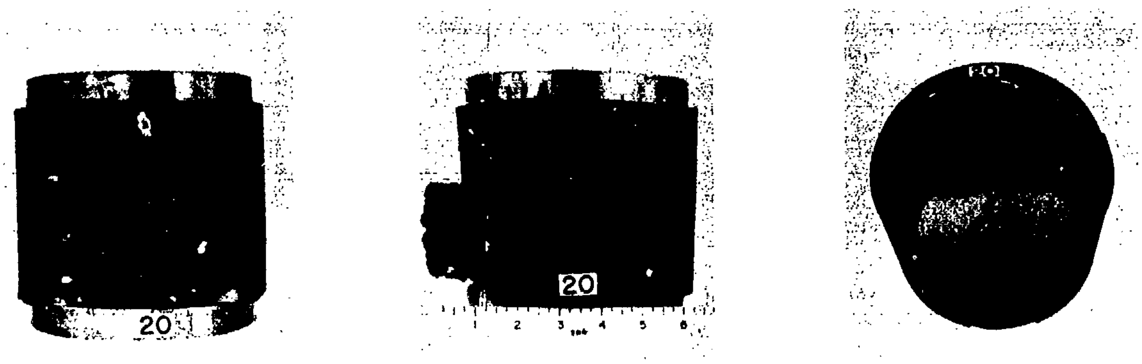
TEST 18 - DAMAGE PRODUCED BY AN SASN LOAD OF 7.45 KILOTAPS

FRONT SIDE TOP



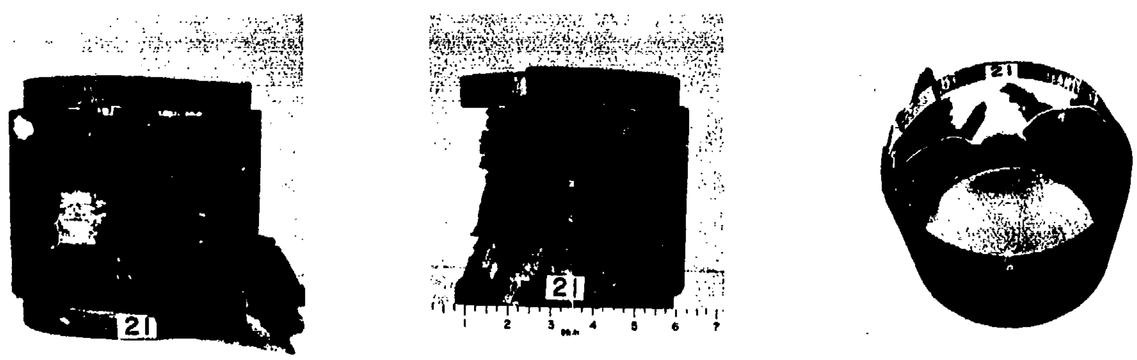
ALUMINUM CYLINDER

TEST 19 - DAMAGE PRODUCED BY AN SE LOAD OF $\sim$4.5 KILOTAPS



LEAD CYLINDER

TEST 20 - DAMAGE PRODUCED BY AN SE LOAD OF $\sim$4.5 KILOTAPS



LEAD CYLINDER

TEST 21 - DAMAGE PRODUCED BY AN SE LOAD OF 4.5 KILOTAPS

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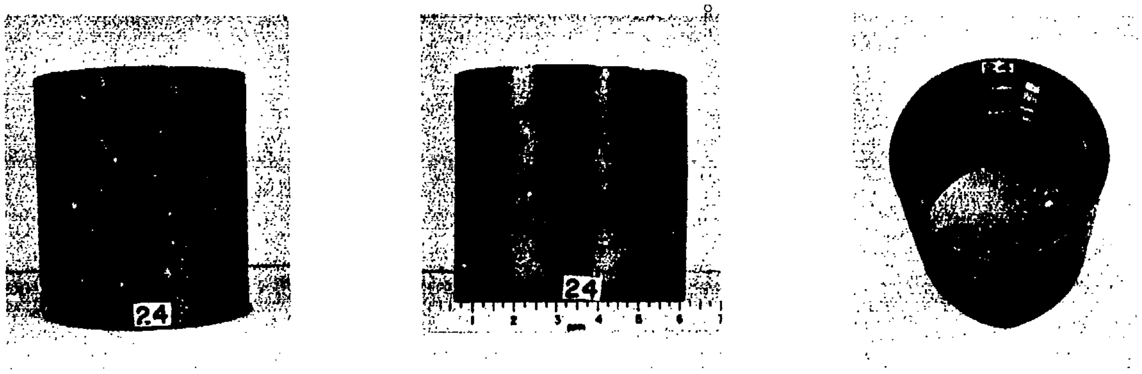
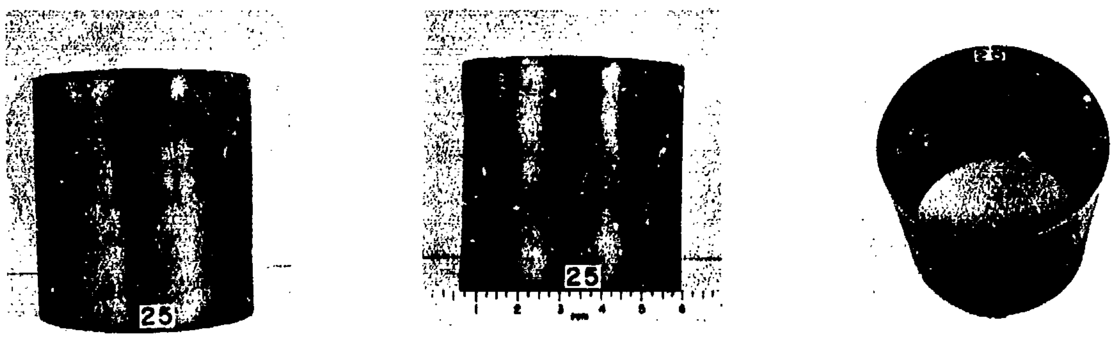
ALUMINUM CYLINDER

TEST 22 - DAMAGE PRODUCED BY A SASN LOAD OF 6.66 KILOTAPS



LEAD CYLINDER

TESTS 23 and 24 - DAMAGE PRODUCED BY SASN LOADS OF 3.12 AND 3.33 KILOTAPS



LEAD CYLINDER

TEST 25 - DAMAGE PRODUCED BY A SASN LOAD OF 3.38 KILOTAPS

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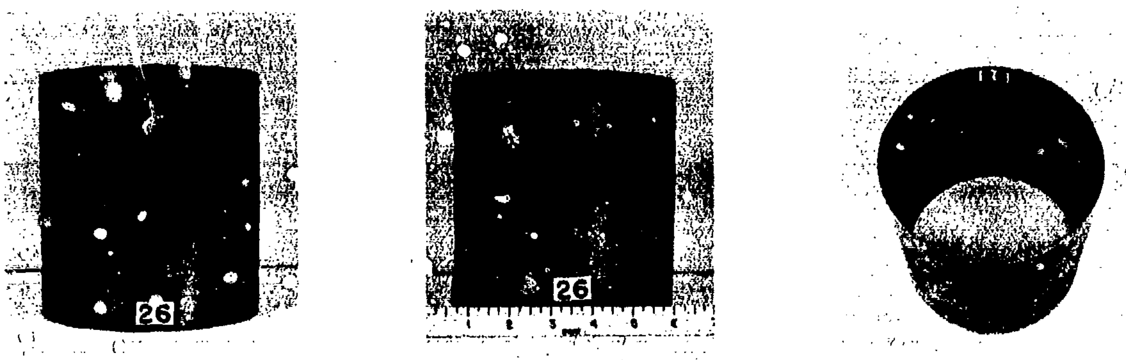

LEAD CYLINDER

TEST 26 - DAMAGE PRODUCED BY A SASN LOAD OF 4.18 KILOTAPS

ALUMINUM CYLINDER

TEST 27 - DAMAGE PRODUCED BY A SASN LOAD OF 4.44 KILOTAPS

ALUMINUM CYLINDER

TEST 28 - DAMAGE PRODUCED BY AN SE LOAD OF 4.5 KILOTAPS

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LEAD CYLINDER

TEST 29 - DAMAGE PRODUCED BY AN SI LOAD OF 4.5 KILOTAPS

APPENDIX B

Instrumentation Results for
Instrumented Tests

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APPENDIX B

The following data are the strain gage output for instrumented shots which produced data. Table B-1 gives the key for gage location. Positive values of strain are compressional strains and negative tension.

TABLE B-1

GAGE LOCATIONS

Gage No.	θ	h	Direction
1	0	L/4	circumferential
2	0	L/4	longitudinal
3	0	L/2	circumferential
4	0	L/2	longitudinal
5	0	3L/4	circumferential
6	0	3L/4	longitudinal

The photocell output for tests in which SASN was used indicates the relative time at which the lamp was initiated. The rise time of the photocell output data was frequency-limited by the recording electronics.

The ordinates of each figure gives a scale for 25,000 or 50,000 μ strains, as well as a value for some of the peak strains The scale for the abscissa in μ seconds appears at the top of each figure. This time scale is the same for all traces in the figures.

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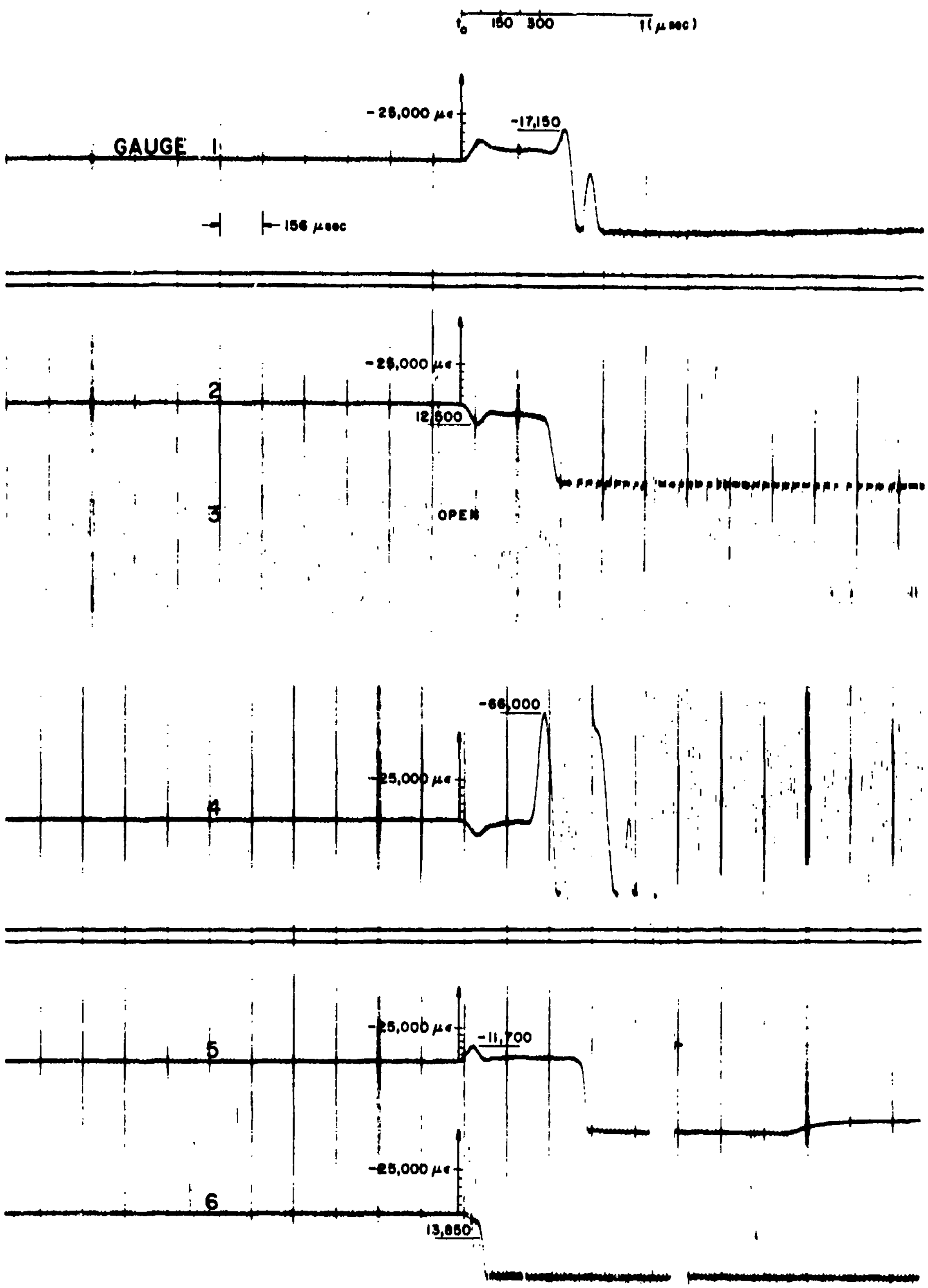

FIGURE B-1. TEST #6 - Al/PHENOLIC CYLINDER, SE CIRCUMFERENTIAL RUNNING LOAD, PEAK SPECIFIC IMPULSE 18 KILOTAPS

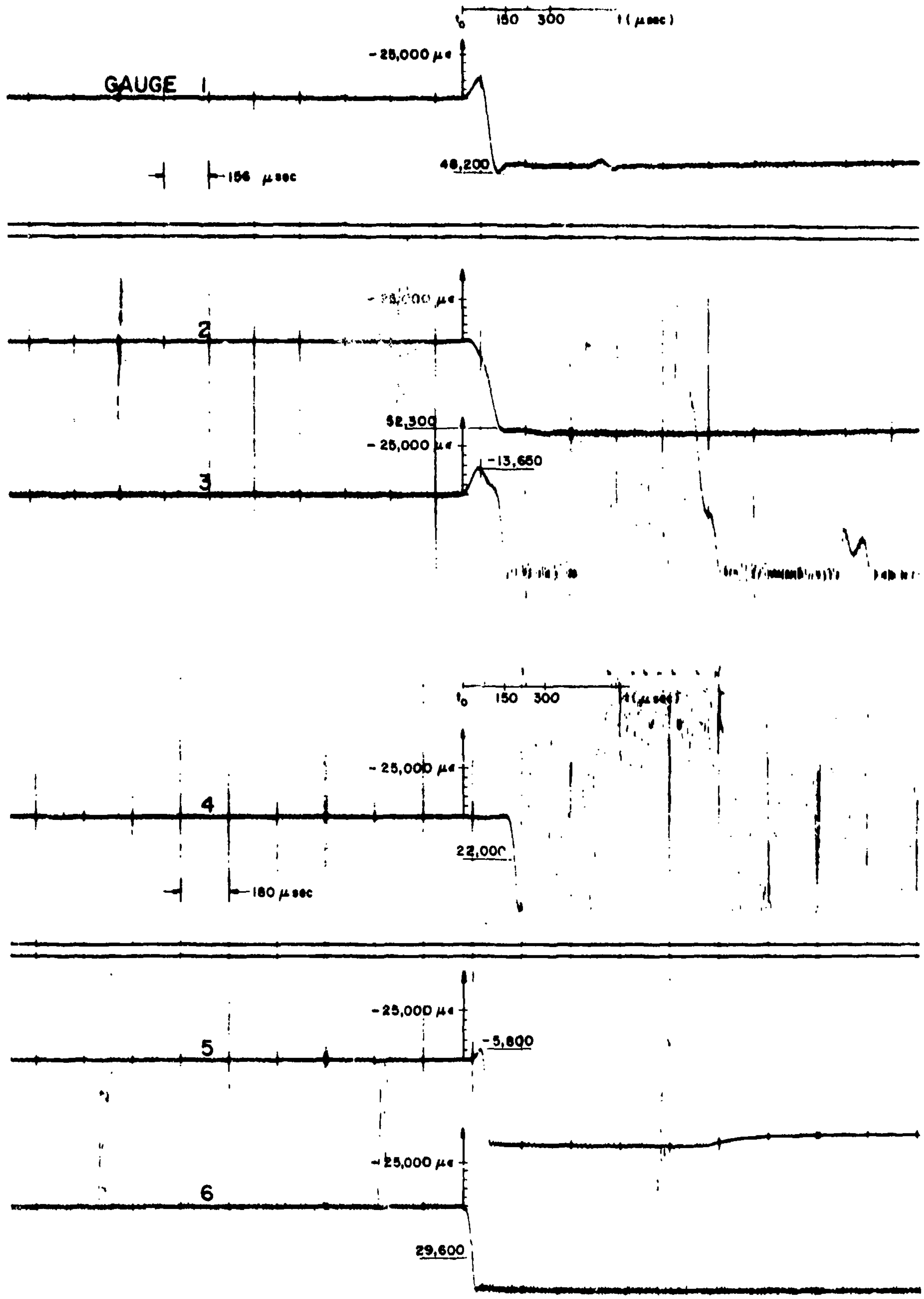

FIGURE B-2. TEST #7 - Al/PHENOLIC CYLINDER, SE LONGITUDINAL RUNNING LOAD, PEAK SPECIFIC IMPULSE 18 KILOTAPS

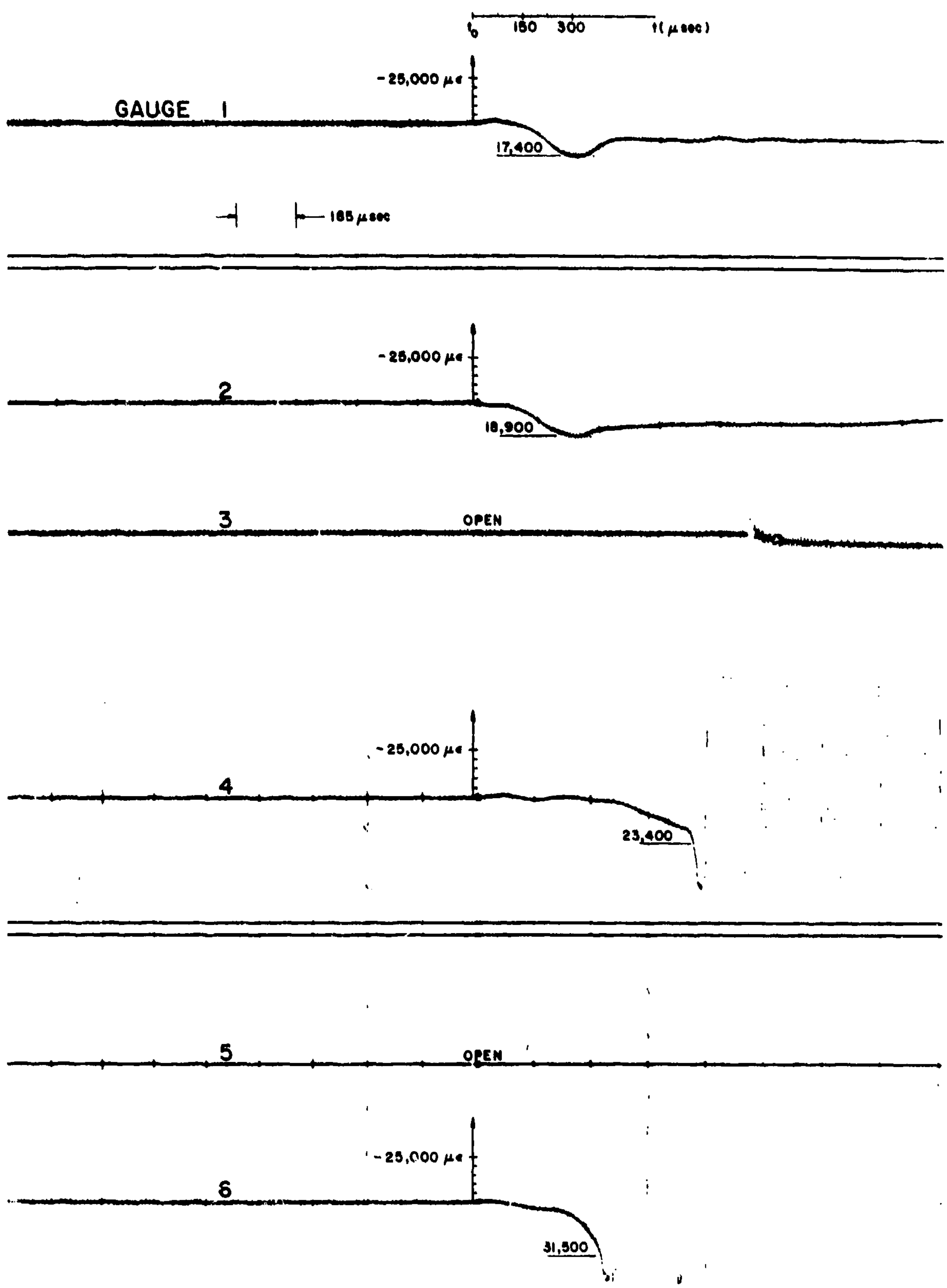

FIGURE B-3. TEST #10 - Pb/PHENOLIC CYLINDER, SE LONGITUDINAL RUNNING LOAD, PEAK SPECIFIC IMPULSE 9 KILOTAPS

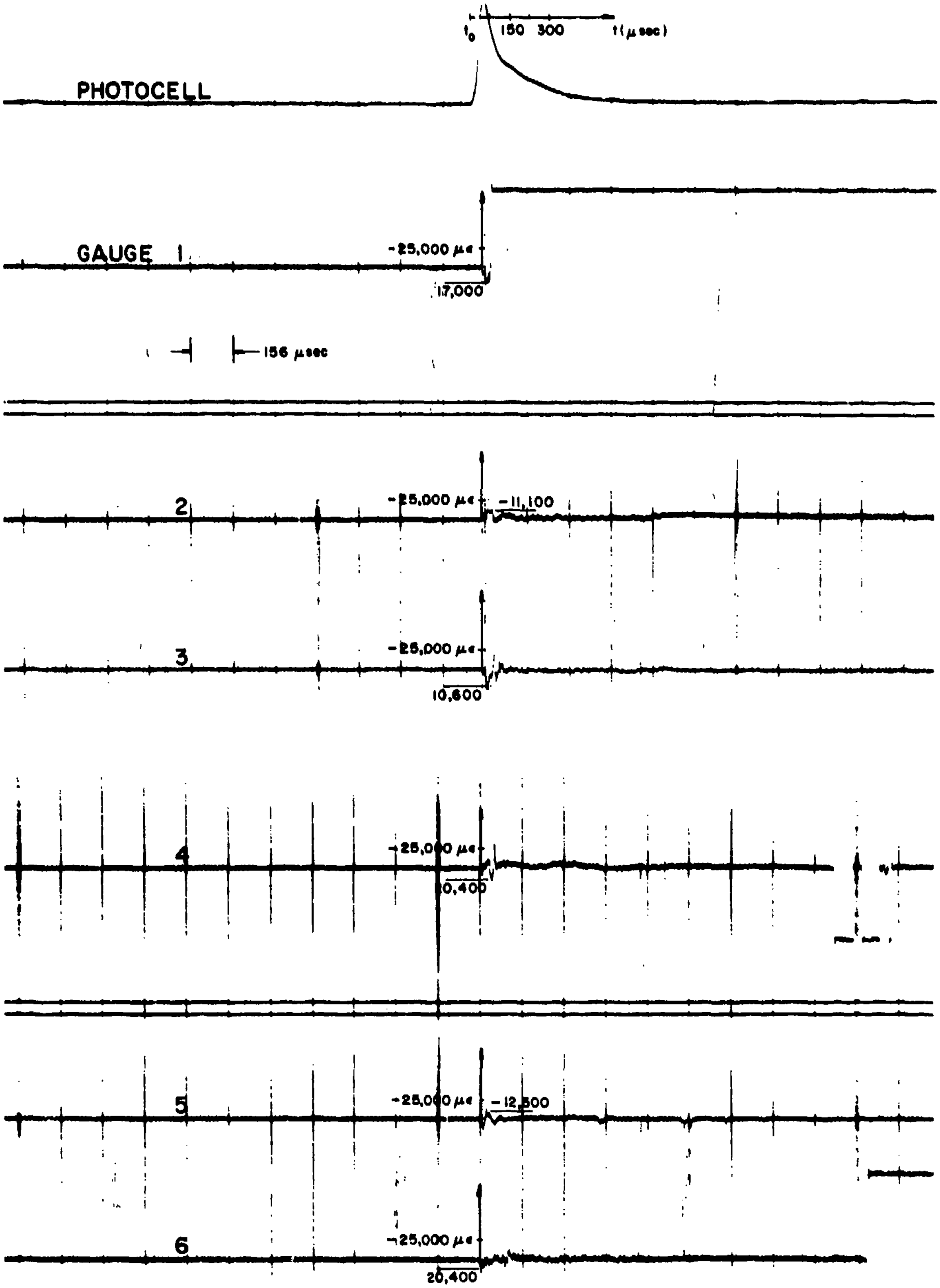

FIGURE B-4. TEST #13 - Al/PHENOLIC CYLINDER, SE CIRCUMFERENTIAL RUNNING LOAD, PEAK SPECIFIC IMPULSE 15.7 KILOTAPS

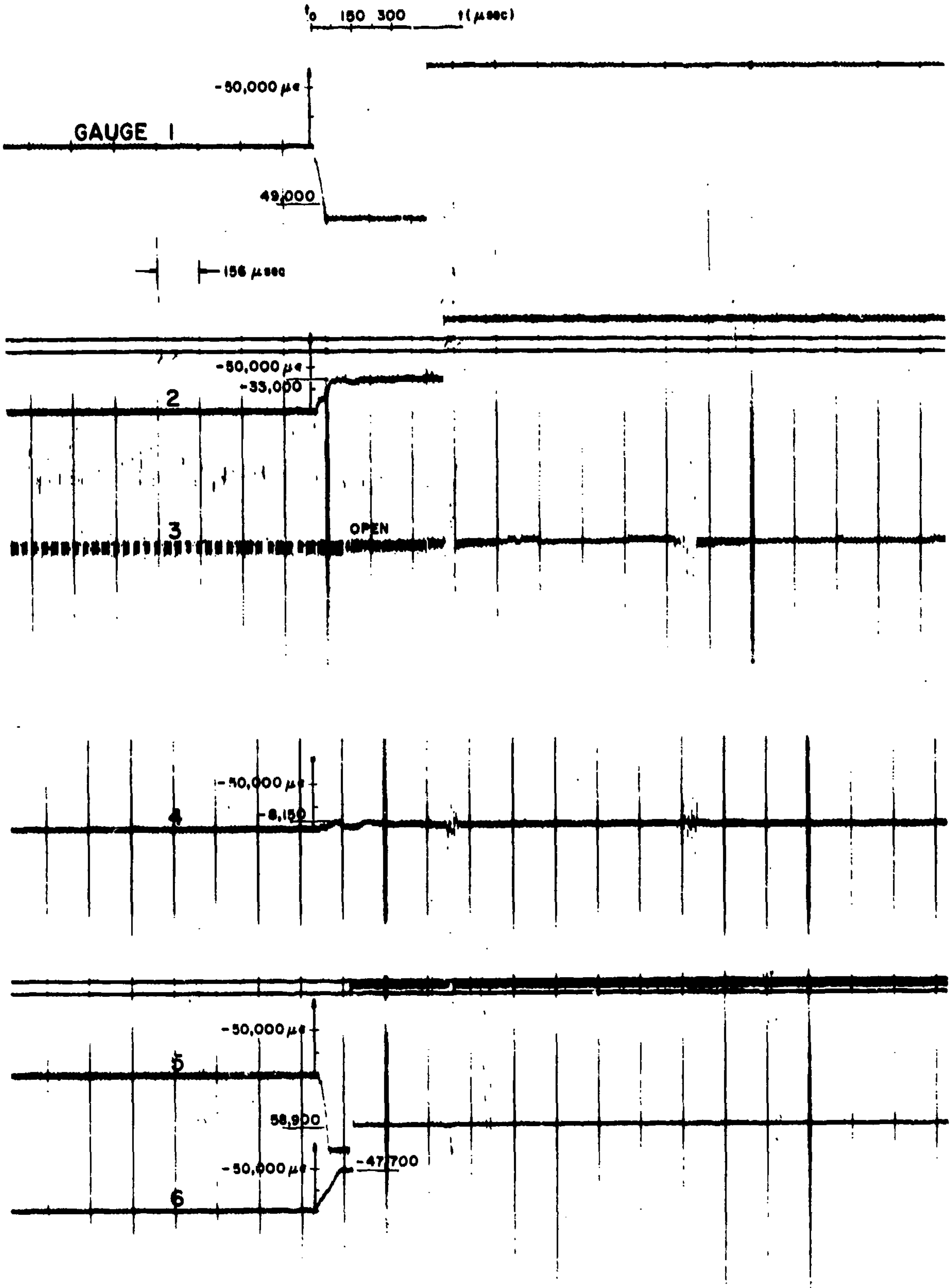

FIGURE B-5. TEST #19 - Al CYLINDER, SE CIRCUMFERENTIAL RUNNING LOAD, PEAK SPECIFIC IMPULSE 4.5 KILOTAPS

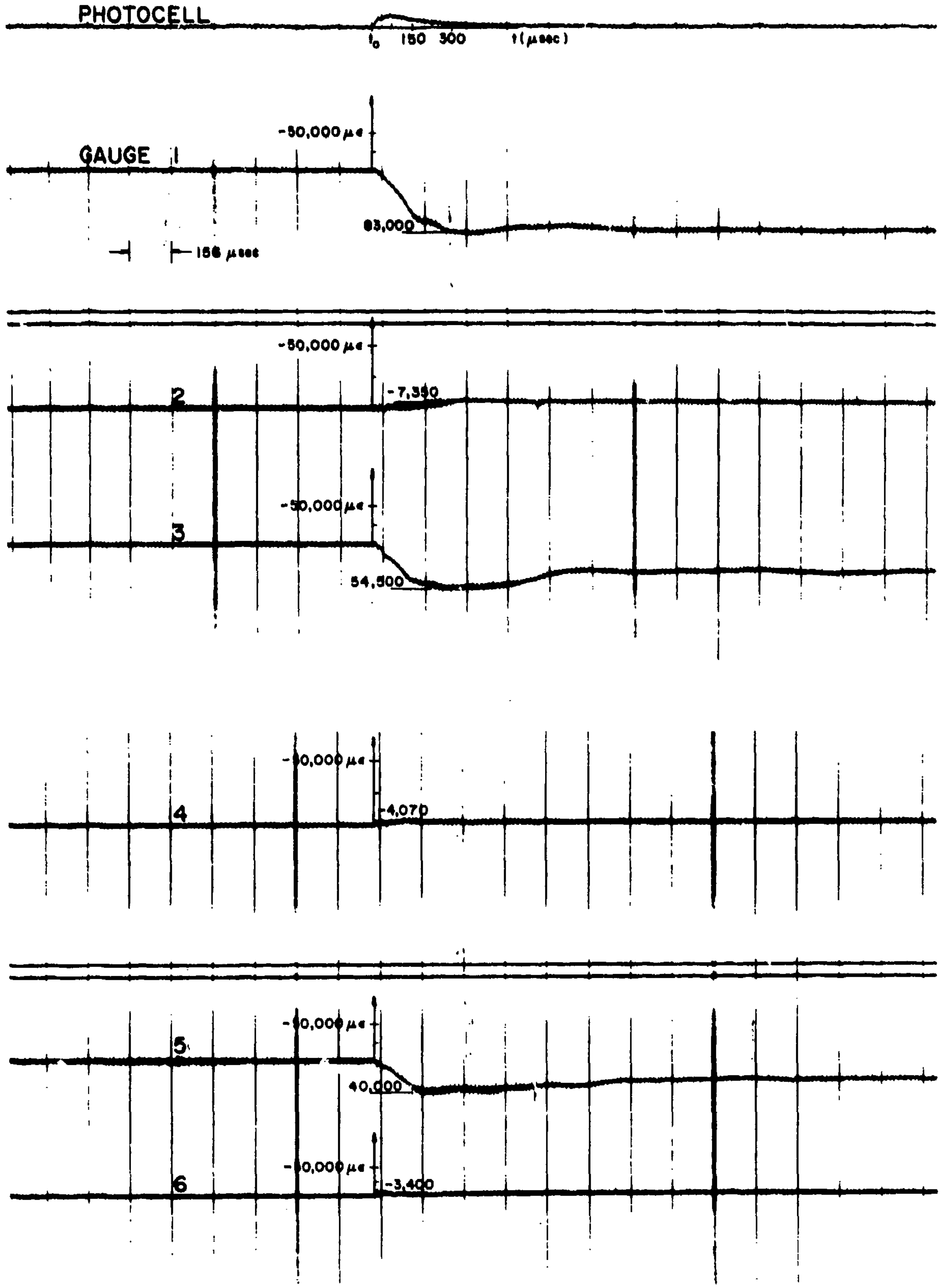

FIGURE B-6. TEST #20 - Pb CYLINDER, SE CIRCUMFERENTIAL RUNNING LOAD, PEAK SPECIFIC IMPULSE 4.5 KILOTAPS

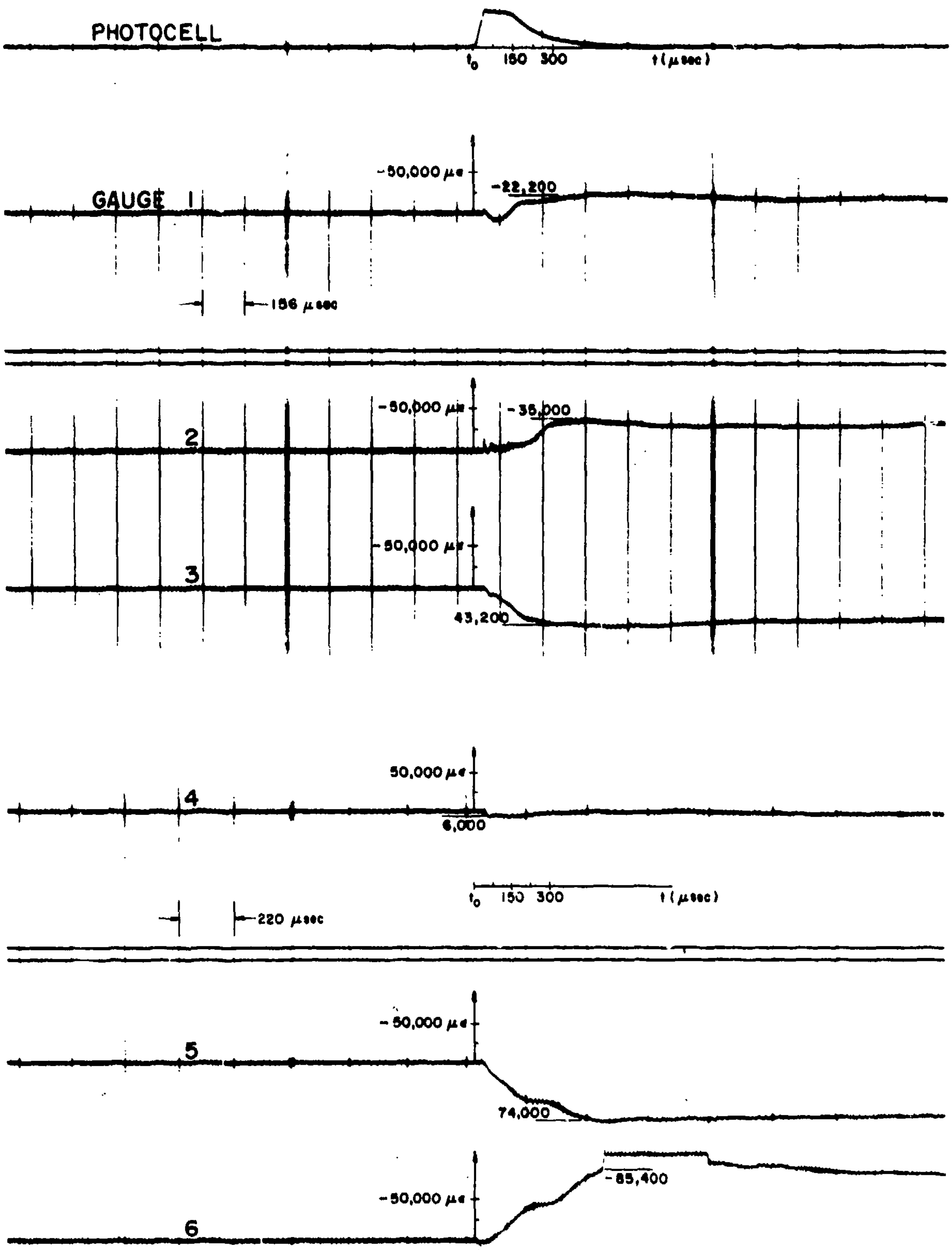

FIGURE B-7. TEST #21 - Pb CYLINDER, SE CIRCUMFERENTIAL RUNNING LOAD, PEAK SPECIFIC IMPULSE 4.5 KILOTAPS

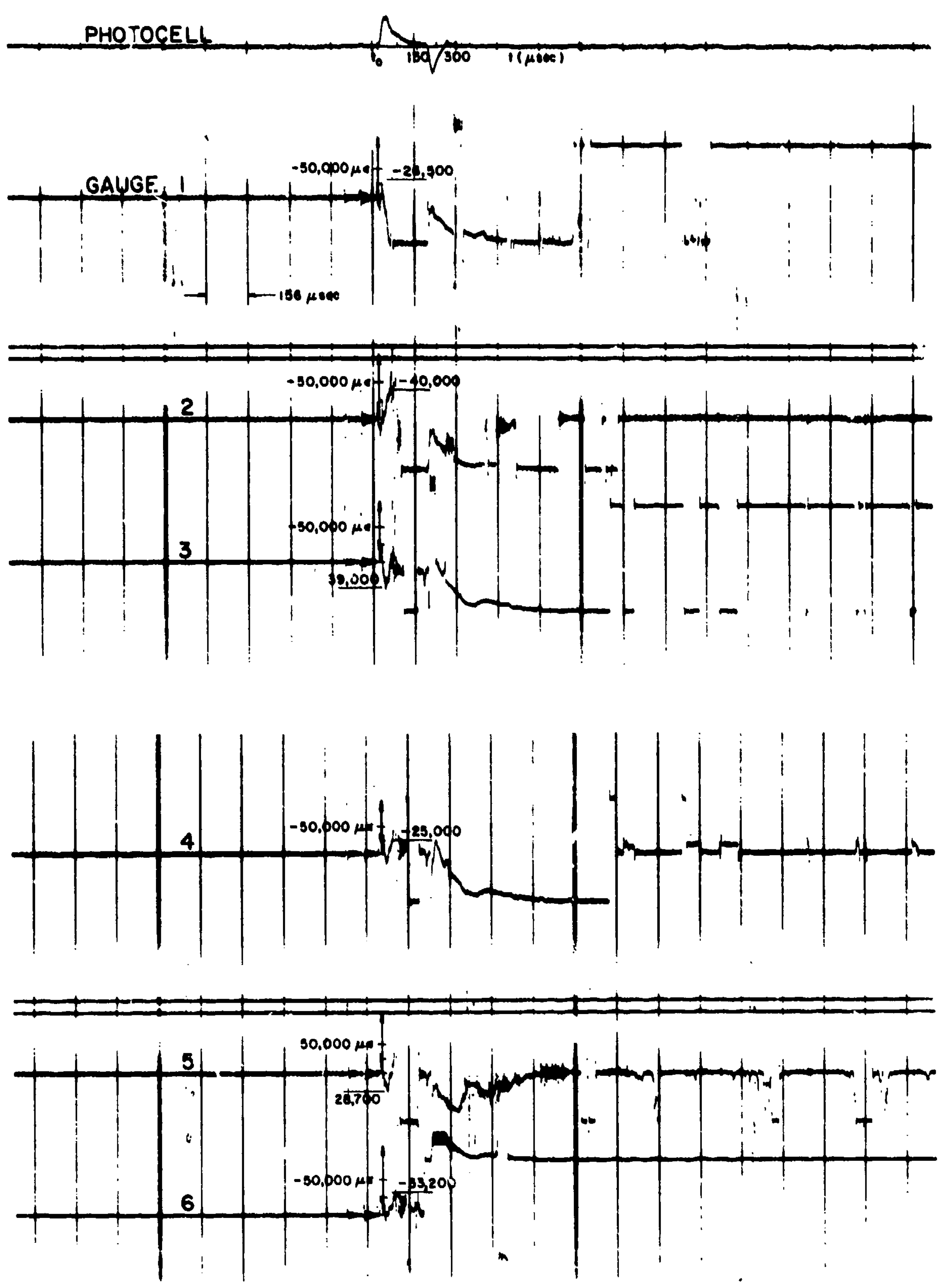

FIGURE B-8. TEST #22 - Al CYLINDER. SASN SIMULTANEOUS LOAD, PEAK SPECIFIC IMPULSE 6.66 KILOTAPS

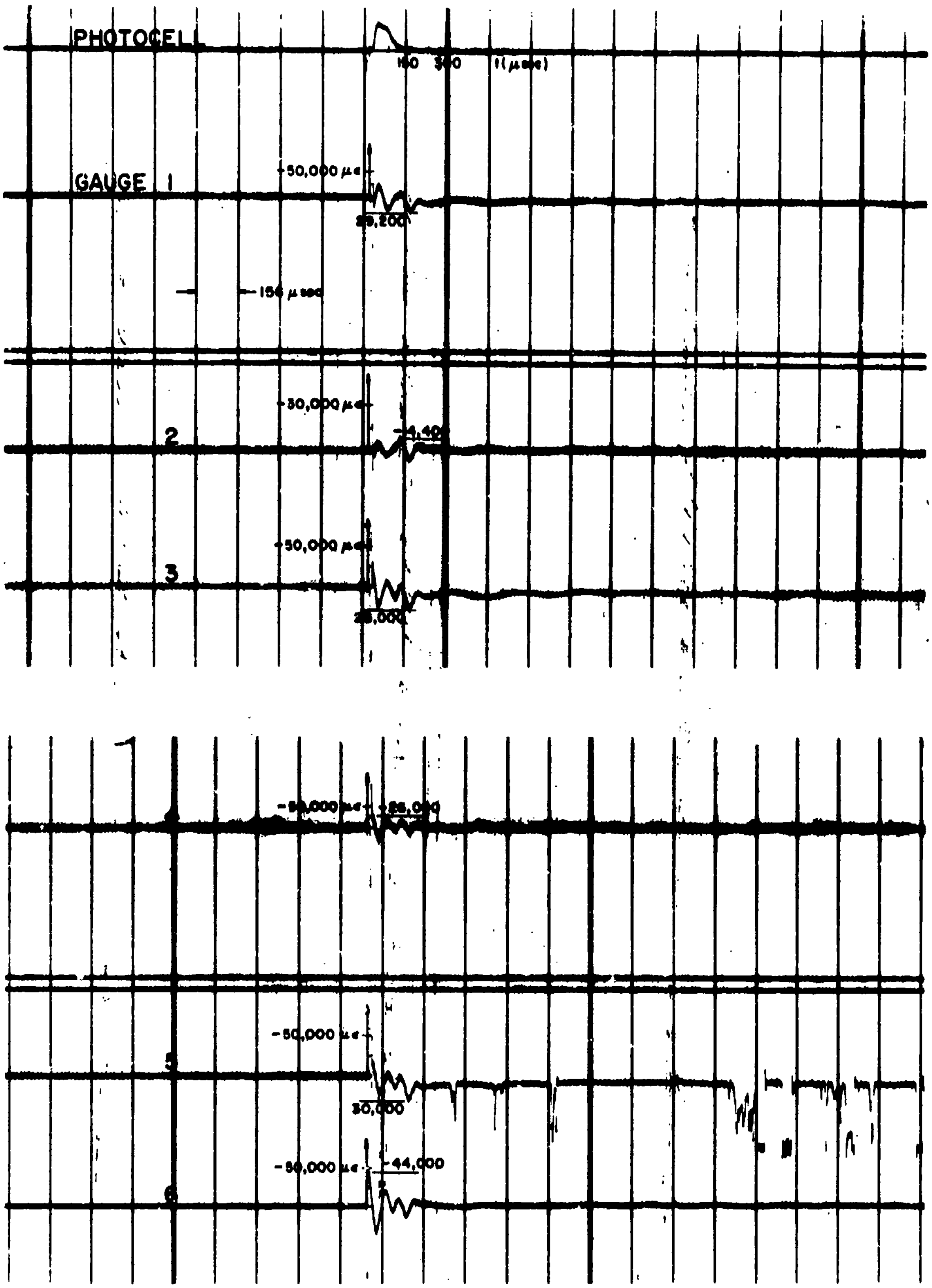

FIGURE B-9. TEST #23 - Pb CYLINDER, SASN SIMULTANEOUS LOAD, PEAK SPECIFIC IMPULSE 3.33 KILOTAPS

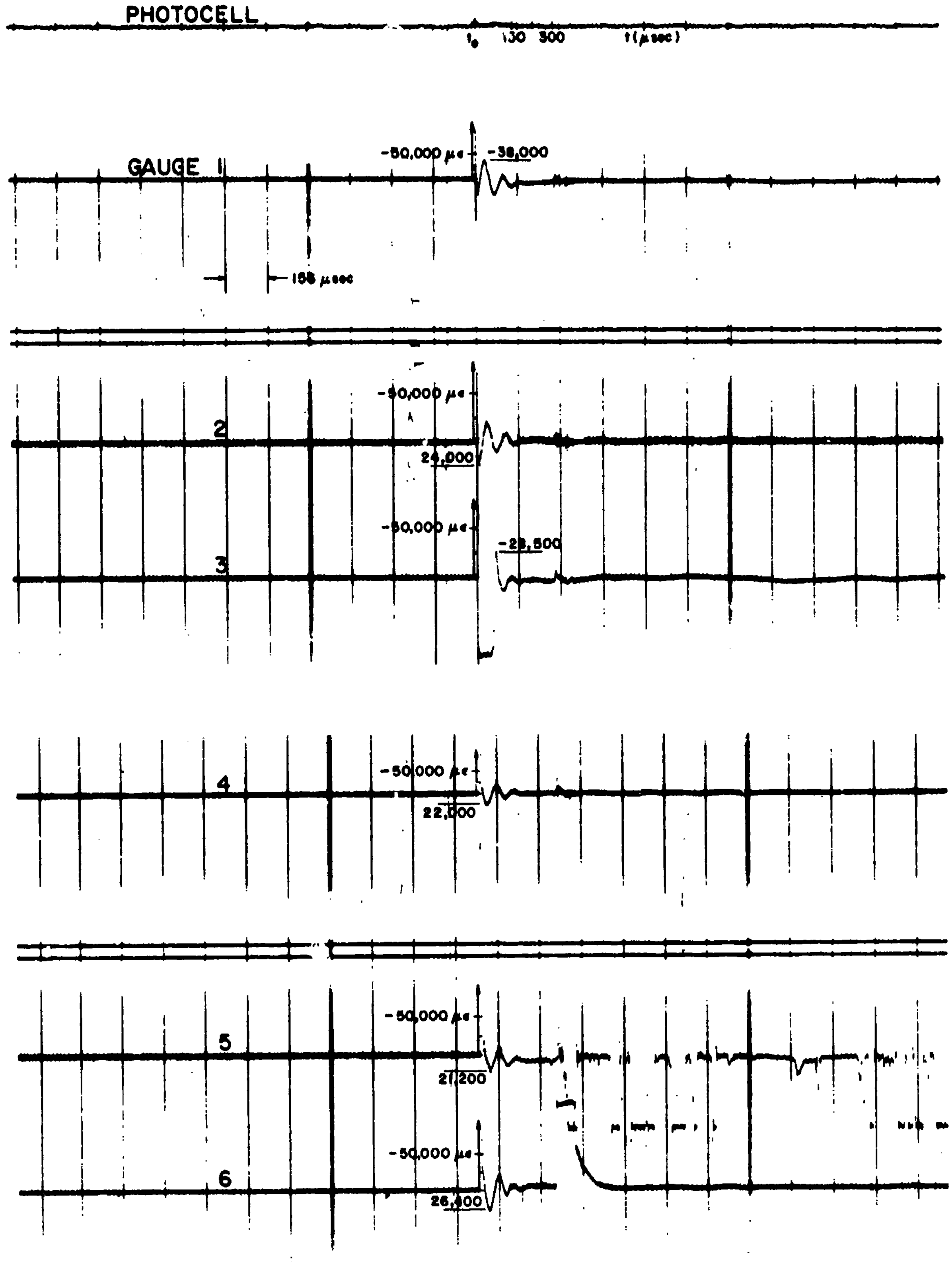

FIGURE B-10. TEST #24 - Pb CYLINDER, SASN SIMULTANEOUS LOAD, PEAK SPECIFIC IMPULSE 3.12 KILOTAPS

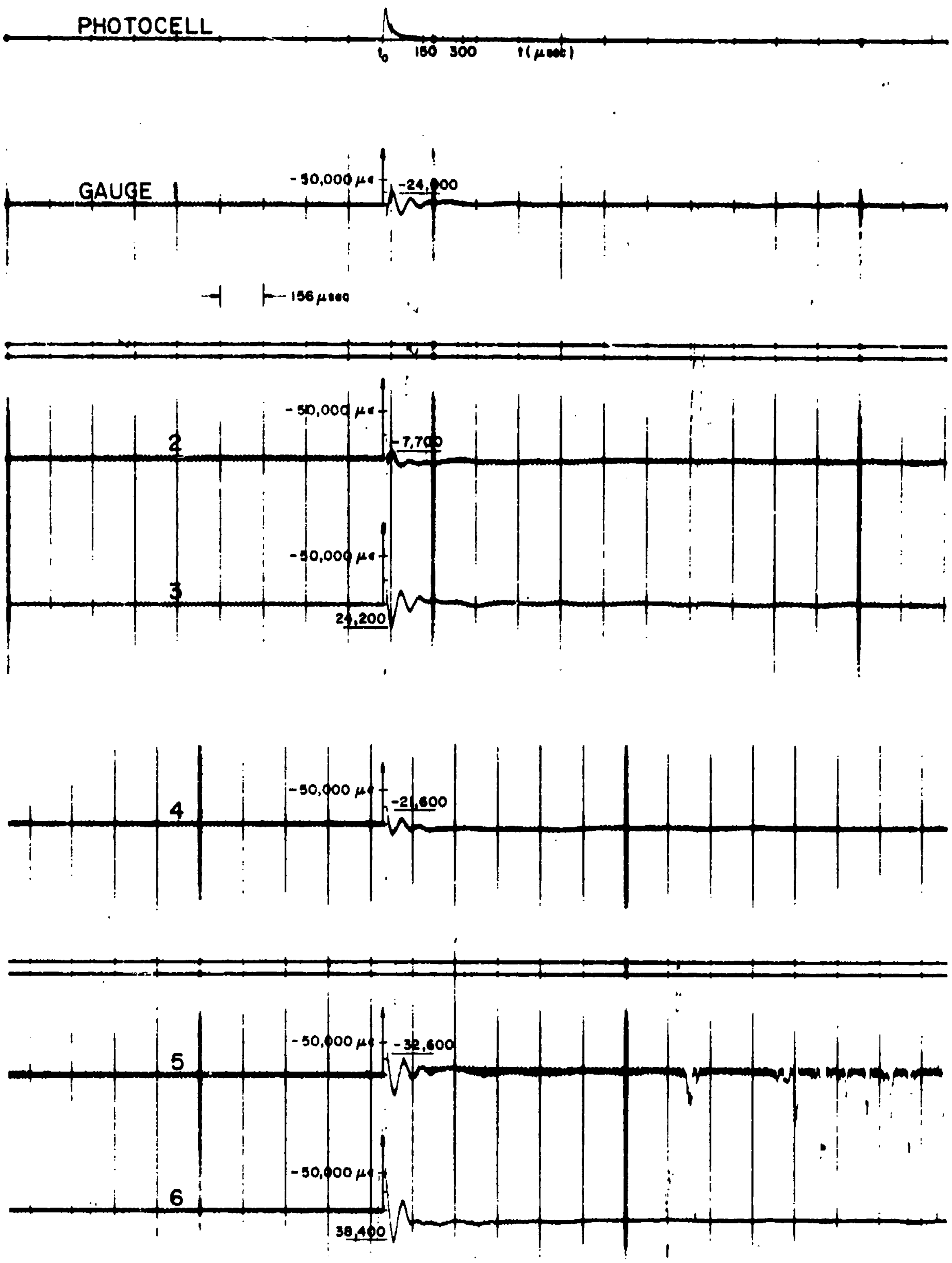

FIGURE B-11. TEST #25 - Pb CYLINDER, SASN SIMULTANEOUS LOAD. PEAK SPECIFIC IMPULSE 3.58 KILOTAPS

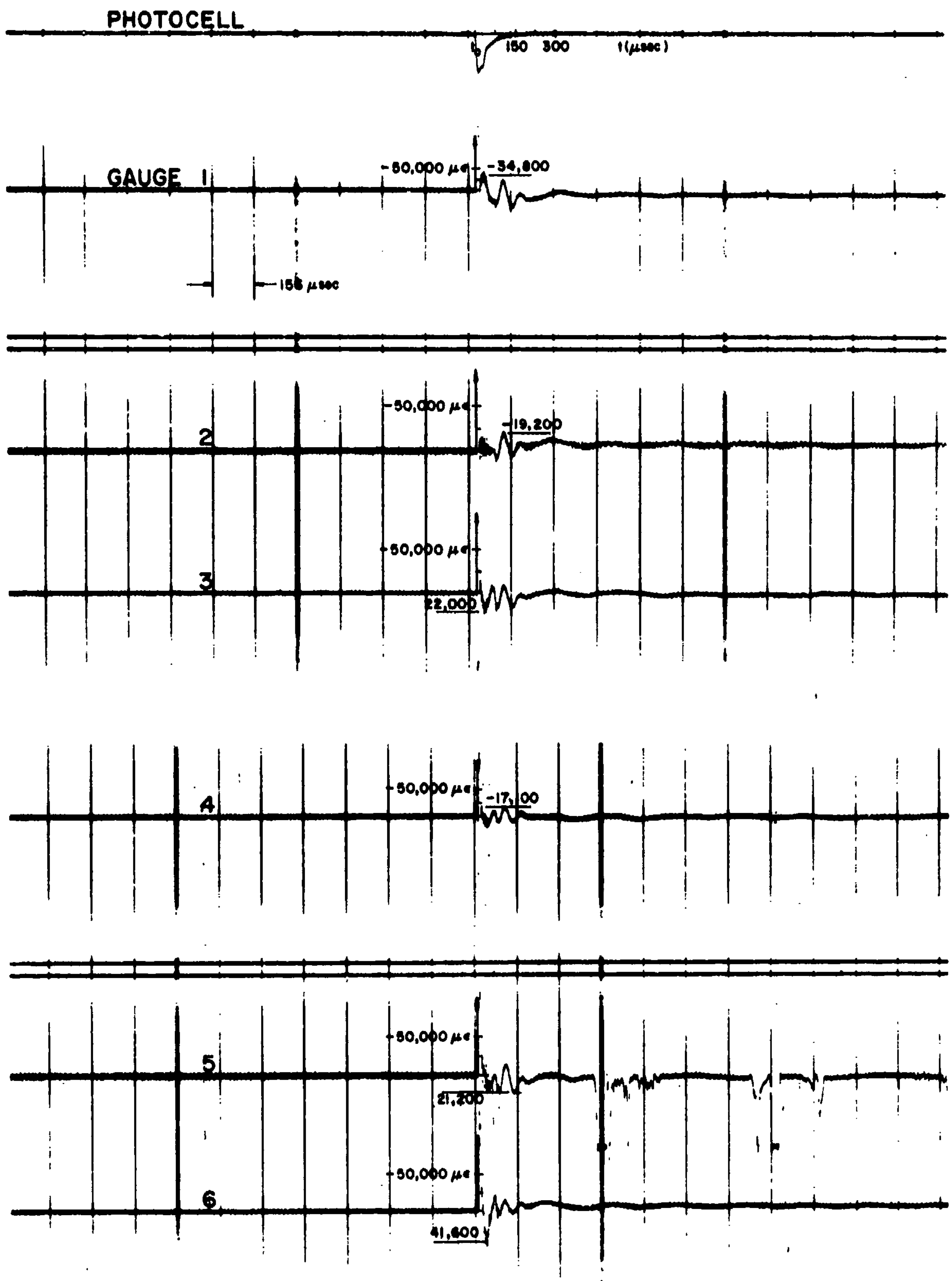

FIGURE B-12. TEST #26 - Pb CYLINDER, SASN SIMULTANEOUS LOAD, PEAK SPECIFIC IMPULSE 4.18 KILOTAPS

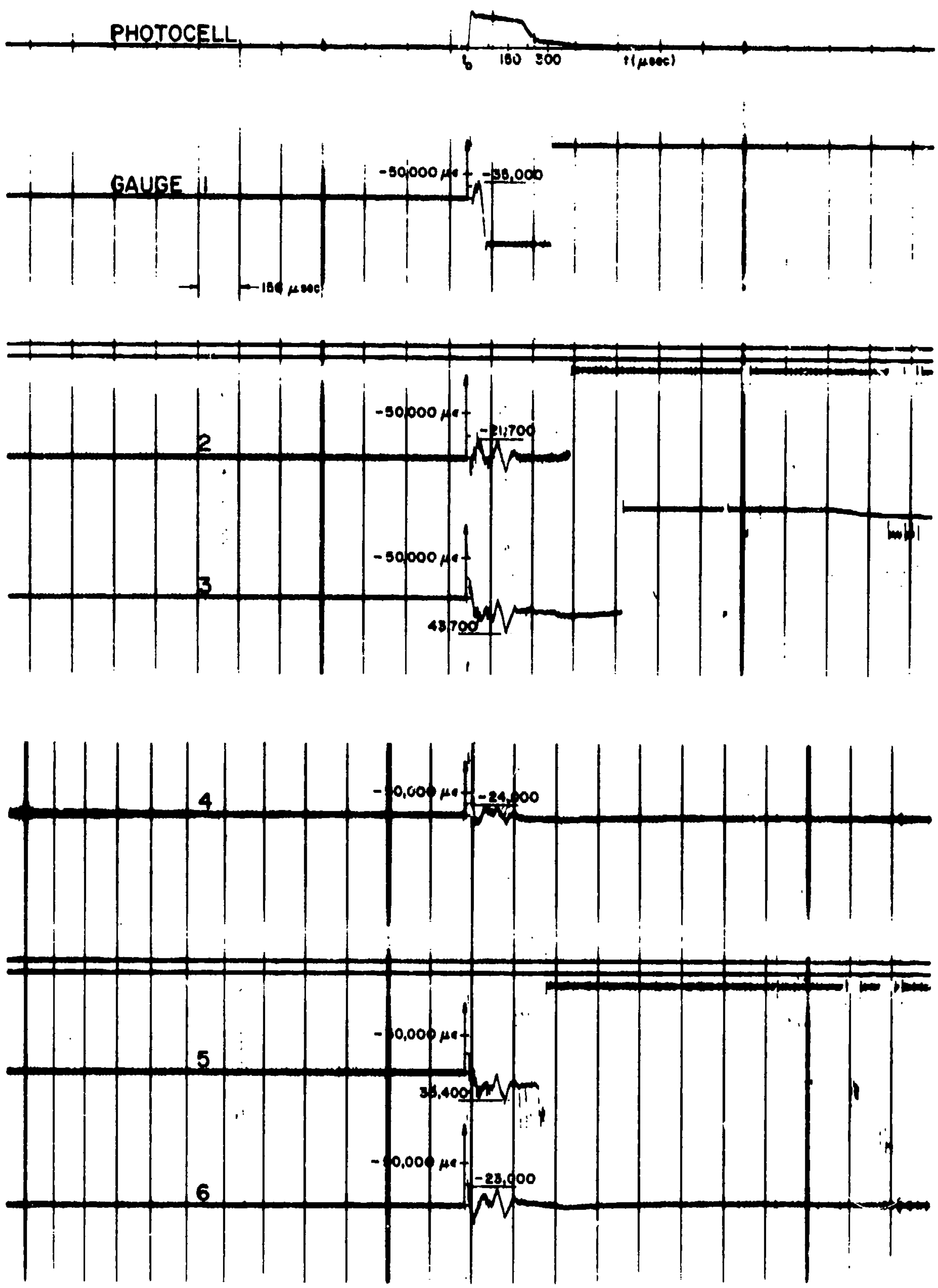

FIGURE B-13. TEST #27 - Al CYLINDER, SASN SIMULTANEOUS LOAD. PEAK SPECIFIC IMPULSE 4.44 KILOTAPS

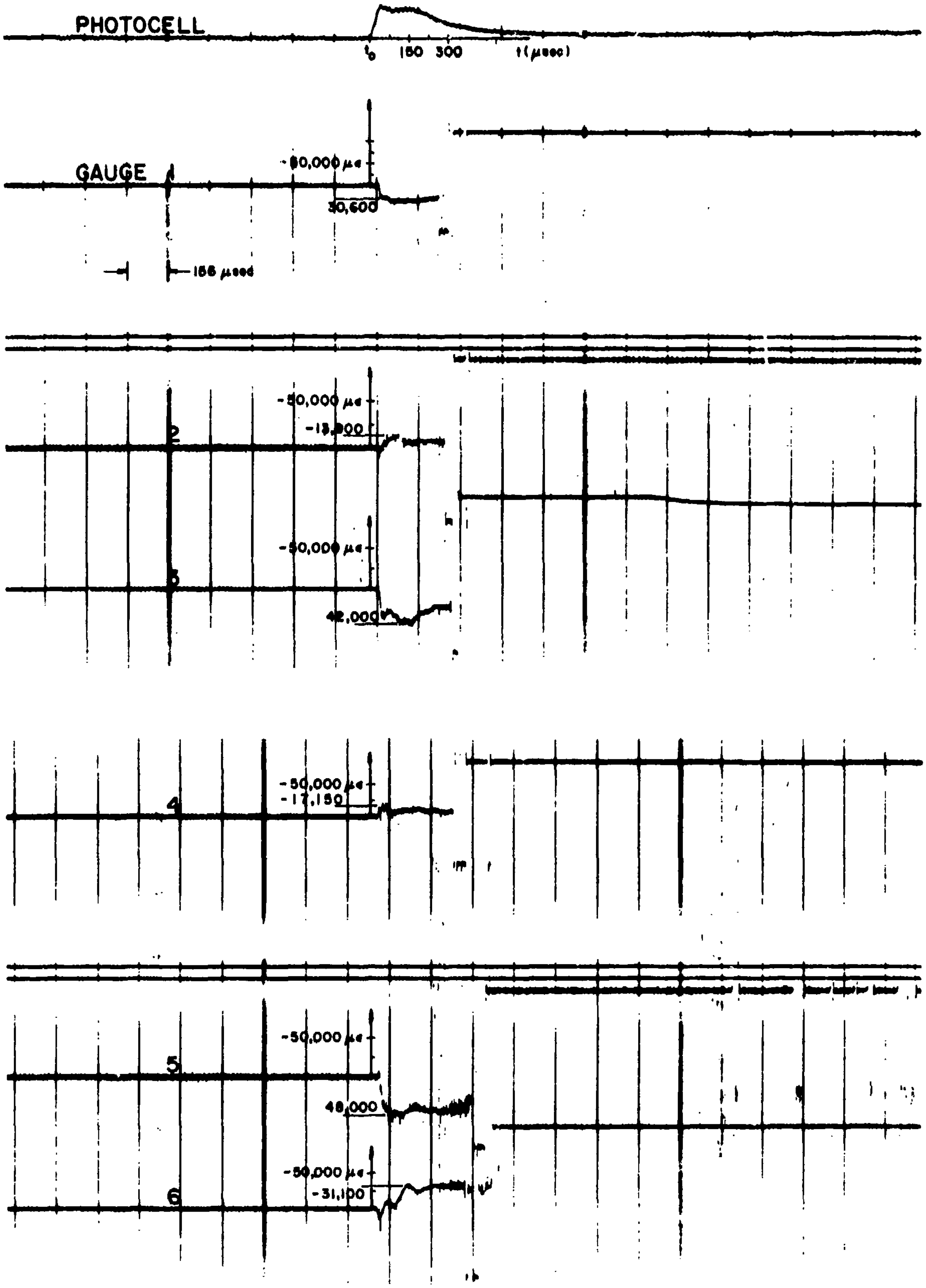

FIGURE B-14. TEST #28 - Al CYLINDER, SE CIRCUMFERENTIAL RUNNING LOAD, PEAK SPECIFIC IMPULSE 4.5 KILOTAPS

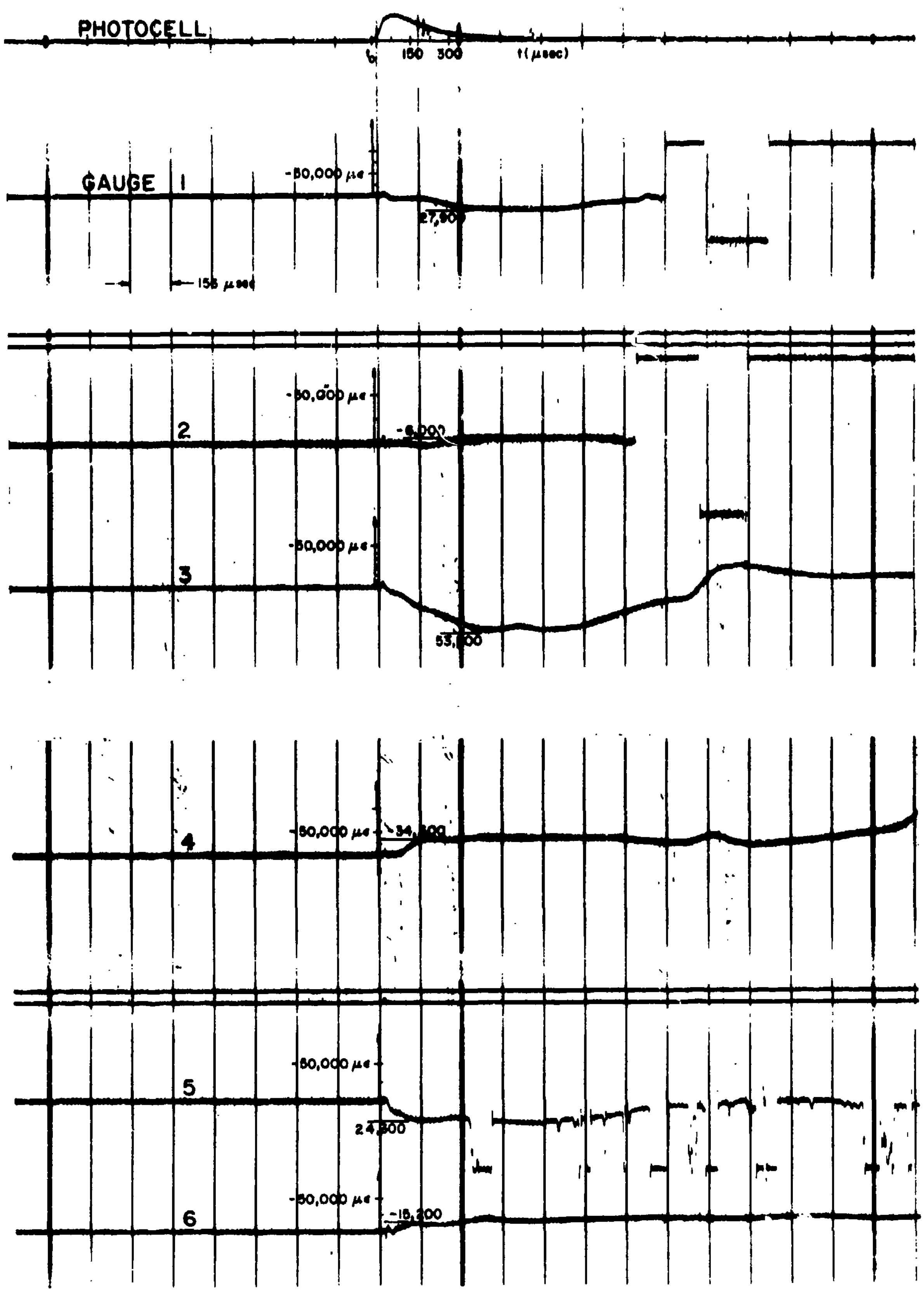

FIGURE B-15, TEST #29 - Pb CYLINDER, SE CIRCUMFERENTIAL RUNNING LOAD, PEAK SPECIFIC IMPULSE 4.5 KILOTAPS